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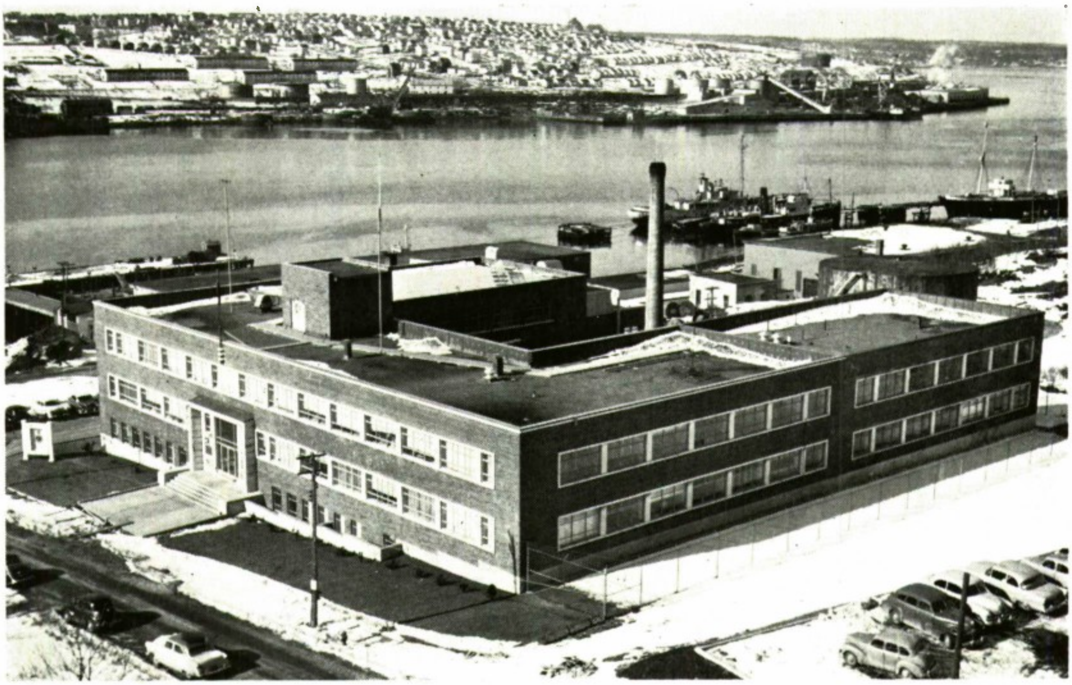

THE DEFENCE RESEARCH ESTABLISHMENT ATLANTIC*

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Introduction

The following words of Sir Francis Drake were seen by the late Dr. Geo. H. Henderson, first Superintendent of the Naval Research Establishment in an office of the Admiralty during World War II.

> I must have the gentlemen to haul and draw with
> the mariners and the mariners with the gentlemen;
> let us show ourselves to be all of one company.

He felt that these sentiments expressed the spirit of the group of National Research Council scientists and naval officers which was formed at Halifax, N.S. in 1940 to help combat the German magnetic mine and later the acoustic mine and torpedo. The hauling was not just a figure of speech, since, prior to the installation of a degaussing range in late 1940, all hands were required to assist with the ropes in keel-hauling ships with heavy magnetometer boxes. In 1941 towed parallel-pipe noisemakers were developed for minesweeping and the ideas these embodied were later used to develop the first anti-acoustic torpedo device to be operated by the allied navies. The large convoys which assembled at Halifax were ranged both magnetically and acoustically by this group, which, in 1943 became H.M.C. Naval Research Establishment.

In the post-war years, the Canadian Government determined that this and other co-operative efforts between the scientific community and the Services should not disappear, so in April 1947, the Defence Research Board (DRB) was formed and the laboratories then under Service management were placed under its control. To ensure the degree of objectivity that such scientific assistance requires, this was set up as a civilian scientific organization within the Department of National Defence.

The Defence Research Board is the agency responsible for basic and applied scientific research as it relates to the defence of Canada. Its scientific programmes are carried out in eight establishments located across the country, each dealing with some specialized phase of research activity. The Naval Research Establishment retained its wartime name

* On 6 July, 1967, the Defence Research Board of Canada re-named six of its eight establishments. The Naval Research Establishment received this title.

until July 1967 but broadened its interest to cover maritime warfare in general, with particular emphasis on anti-submarine warfare. Many D.R.E.A. projects are long term and are of a basic character aimed at the discovery of new knowledge of the physical parameters of the ocean in order to provide a firm basis for development of equipment and tactics. Short term projects of immediate interest to the Services are dealt with by a Service Project Unit and day-to-day testing and technical assistance is supplied through a Dockyard Laboratory Section. The interest in underwater acoustics has been continued and about 55% of the effort at DREA is now devoted to this field. Another 25% is associated with the hydrodynamics of hydrofoil craft and towed bodies.

The professional staff of 56 under the direction of the Chief Superintendent, Dr. J. G. Retallack, consists of physicists, applied mathematicians, engineers, chemists, metallurgists, hydrodynamicists and oceanographers. They are supported by technical staff in the ratio of two support staff members for each scientist. In addition six Service officers act in liaison or scientific capacities. Including non-scientific administrative staff, the total exceeds 200.

Facilities

The main building of DREA, which is shown opposite, is in Dartmouth, N.S., across Halifax Harbour from H.M.C. Dockyard, the major naval base of the Canadian Armed Forces. The DREA Dockyard Laboratory is located within the Dockyard area.

Two sea-going research ships, Canadian Naval Auxiliary Vessels NEW LISKEARD and FORT FRANCES, each of about 1,350 tons deep displacement, are well outfitted to carry out acoustic experiments in the ocean. CNAV NEW LISKEARD, which served NRE continuously for 20 years, will soon be replaced; construction has started on a new 2,130 ton research vessel, CNAV QUEST (Fig. 1), which will be specially quietened to reduce radiated noise.

DREA operates a large acoustic barge which is anchored in Bedford Basin at the head of Halifax Harbour. The barge is 118 ft. long and 56 ft. wide, almost entirely covered by a deckhouse, and contains a 60 ft. × 30 ft. well, which is spanned by motorized trolleys with powered mounts for hydrophones and sound sources as shown in Fig. 2. This facility allows acoustic measurements to be made of devices weighing up to 7½ tons. It can accommodate the largest transducers and domes used by the Canadian Forces. It has also been used for acoustic measurements of underwater explosive charges.

To allow laboratory tests of equipment for use deep in the ocean, a large high pressure test tank has been installed near the main building. The tank, which is 3 ft. inside diameter by 8 ft. deep, has 7½ in. walls and was machined from a solid billet. It is designed for a maximum pressure of 8,500 lbs/sq in., corresponding to an approximate depth of 3,200 fathoms. The head, which has a powered breechblock closure, is fitted with glands to permit testing of cable-connected equipment.

The Establishment's specialized mathematical requirements are met by a group of applied mathematicians supported by a Ferranti-Packard *FP*-6000 computer system with a *Fortran* compiler. Sophisticated instrumentation is used to record data at sea on magnetic or punched tape which can be processed through the computer on returning to the laboratory. A small analog computer is employed in the study of dynamics of hydrofoils and a *PDP*-8 process control computer is used as a research tool in the laboratory and at sea.

Post-war Activities

Research at NRE in the first years after World War II culminated in two projects of quite different character—(a) cathodic protection of ships' hulls and (b) variable depth sonar—each of which has passed through development and become operational in Canadian naval vessels.

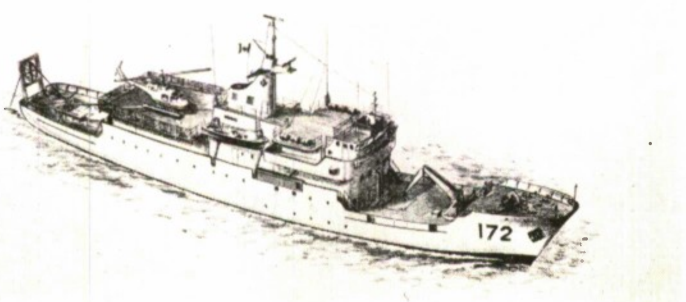

FIG. 1. CNAV "Quest," an artist's conception of the research ship being built for DREA

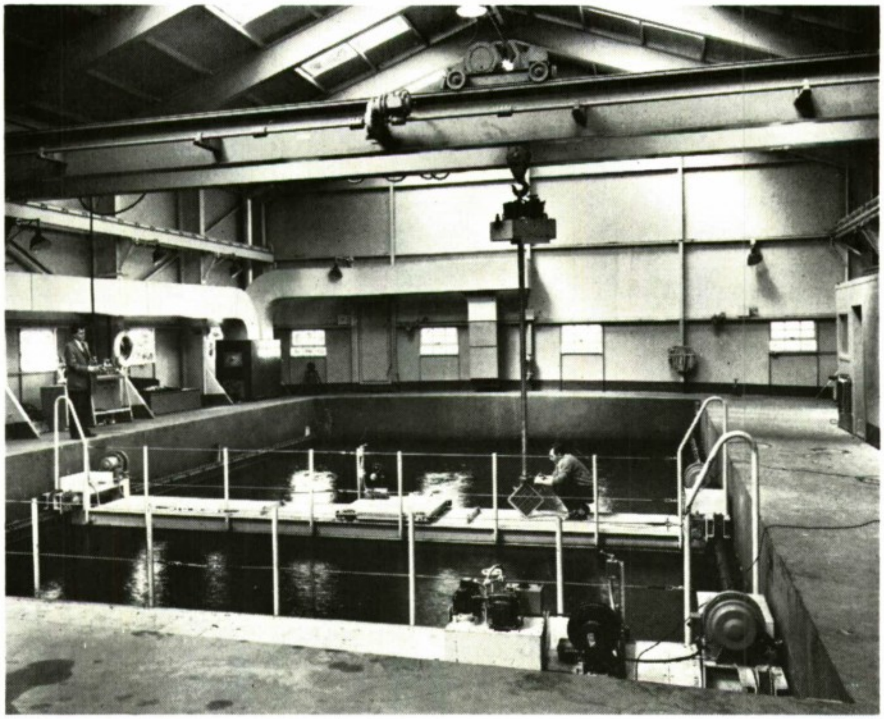

FIG. 2. The bottomless well of the Acoustics Barge spanned by platforms and cranes for handling transducers and domes.

Cathodic Protection of Ships

In 1945 NRE physicists showed that the strength of electrical potential fields around ships' hulls was related to the amount of hull corrosion present. This led to a study of the phenomenon and to the design of a system giving complete protection from corrosion to the underwater hull of a ship, with consequent saving of large sums of money in replacement of plates *etc.* and marked reduction of out-of-service time.

When a non-homogeneous metal structure is placed in an electrolyte such as seawater, electrical currents will flow between local anodes where oxidation and hence corrosion occurs and local cathodes where reduction takes place. The hull of a ship as a whole can be made a cathode either (a) by use of sacrificial anodes of a less noble metal such as magnesium or zinc, usually fitted to bilge keels and near the propellers, to produce a counter potential, or (b) by an impressed voltage between the hull and a number of steel, graphite, or lead-silver anodes, such voltage being supplied from a power source within the vessel. Cathodic protection systems based on these principles have been fitted to all vessels of the Canadian Forces and have also been adopted by other navies and commercial steamship lines.

When a ship is cathodically protected, OH ions are produced at the surface of the hull and hence special alkali resistant paints are required. Such paints have been developed in collaboration with paint manufacturers and are used to give a relatively even distribution of current over the hull. To take full advantage of the improved anti-corrosion techniques, improvements in anti-fouling paints were also made, so that a two-year period between dry-docking would be a practical maintenance period.

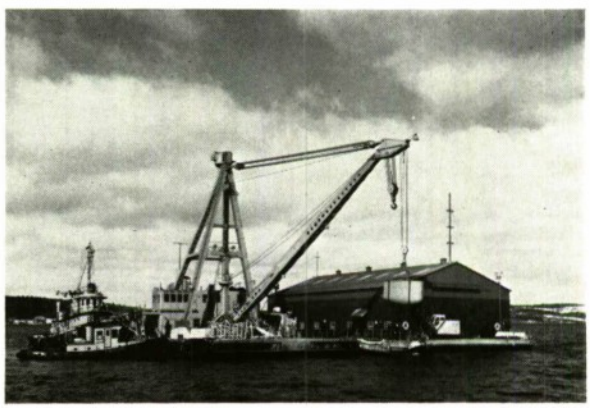

FIG. 2(a). The acoustics barge

Variable Depth Sonar

During the 1950's, NRE acousticians and engineers were principally occupied in experimental work, design studies and construction related to variable depth sonar (*VDS*). The initial aim of the project was to find a way of coping with the strong thermoclines which exist near the surface of the ocean, particularly in the Canadian east coast area, and adversely affect the performance of hull-mounted sonar. Other merits of VDS, such as the elimination of "quenching," were also recognized. Experiments were carried out with various types of bodies and methods of fairing to achieve a towed operational system. With the fitting of the Canadian designed *AN/SQS* 504 in RCN and RN ships, the research phase was considered to be completed and *VDS* for destroyer escort vessels ceased to be a project of NRE.

Underwater Acoustics

During the past seven years a large part of the underwater acoustics research has been aimed at the measurement of the acoustic parameters of the ocean which affect the performance of long range sonars. Explosives were used as sound sources as it was desired to carry out studies over a wide frequency band. Much of this effort has been devoted to studies of reverberation caused by sound scattered from the surface, volume and bottom of the ocean. Determinations have been made of the dependence of surface reverberation on wind speed(1). Values of bottom and volume reverberation have been determined as functions of frequency and geographical location(2). Most measurements have been made in the north west Atlantic between Bermuda and Nova Scotia but cruises have ranged as far afield as Iceland and Gibraltar.

One of the most striking features of the reverberation study has been the variation in the level of volume scattering with frequency and the change in this pattern from day to night as illustrated in Fig. 3. This volume reverberation is believed to be caused by fish which inhabit specific horizontal layers in the ocean and whose swimbladders resonate at frequencies depending on the size and depths of the fish. As certain of these fish move toward the surface at night, the resonance shifts to lower frequencies with a consequent change in the reverberation spectrum.

As an associated project, echo-ranging experiments have been conducted using directional sound sources and receivers immersed deep in the ocean. For this research, engineers at NRE have fitted CNAV Fort Frances with the large "pod" shown in Fig. 4. This unit, which has been lowered to 13,000 feet, holds 96 explosive charges each of which can be released and fired on command from the ship. In the top section of the pod there is a 6 ft. diameter plane hydrophone array with which to record the echo levels and the sonar background.

Since 1954, a number of investigations have been carried out of the acoustic parameters which affect submarine detection in shallow water. Measurements were made initially from an installation near the mouth of Halifax Harbour and later from field stations on the coasts of Prince Edward Island and Cape Breton. These studies have shown the dependence of sound propagation and reverberation on such parameters as the bottom type and the sound velocity structure of the water column and of the dependence of the ambient sea noise on wind speed. Some of the more recent studies have been concerned with values of these parameters under an ice covered sea surface such as is found in winter at these last two sites(3) (4).

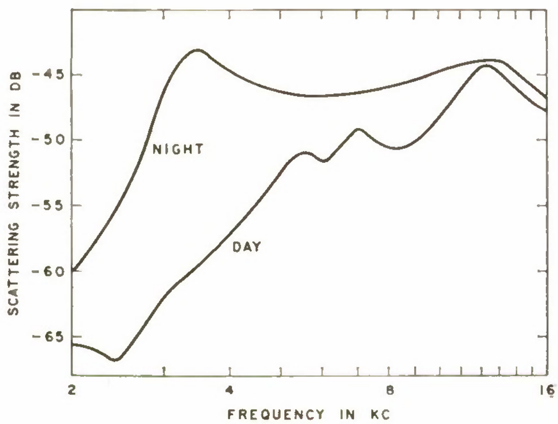

FIG. 3. Scattering strength of the scatterers in the water column from the surface to the bottom of the deepest scattering layer present as a function of frequency.

FIG. 4. Pod with explosive charges and trainable hydrophone array being lowered over the stern of CNAV " Fort Frances ".

The possibility of using hydrofoil craft in an antisubmarine rôle has motivated an examination of the noise in bodies moving through the water at high speeds. During the past two years measurements have been carried out both from bodies towed by the hydrofoil craft BADDECK and from buoyant bodies pulled well below the surface and released.

Acoustic studies of the submarine target, from the communication theory point of view have been carried out in support of advanced sonar design. Using a modified variable depth sonar combined with digital processing equipment, studies of transmission paths, reverberation and echoes have been made to relate their characteristics to the performance of matched-filter detection systems.

The present oceanographic effort is in support of the acoustics programme and is centered on the direct determination of the velocity of sound in the ocean. An equipment package has been constructed which consists of cable-connected instruments to measure the velocity of sound, the temperature and the depth to depths of 10,000 ft. The data are recorded on punched tape and processed using the digital computer.

Transducers

The NRE transducer team has specialized in the use of piezo-electric ceramics of various types in the development of transducers for both operational and research purposes. With the assistance of other Canadian workers, an improved barium titanate composition was produced in 1956 for the variable depth sonar. This composition has since become widely used in Canada and the U.S.A. NRE was also among the first to develop the technique of prestressing the ceramic by applying a compressional bias to the ceramic stack. This technique improves the power handling ability and ruggedness and is now in common use in ceramic transducer designs.

Research at this establishment has required projectors for operation deep in the ocean with emphasis on high power, wide bandwidth and an ability to radiate sound directionally, all this without excessive size or weight. The directional requirement has posed a particularly severe problem since the backing of air used to block back-radiation in conventional transducers is difficult to achieve at great depths. Hence unusual shapes and combinations of materials have had to be used to form free-flooding transducers, such as (a) a conical projector shown in Fig. 5[5] which radiates to the far field chiefly from the flat face forming the base of the cone and (b) an array of open ceramic rings with closely coupled mechanical and cavity resonances.

For deep-ocean application, a variety of hydrophones has been designed. One, which is used in

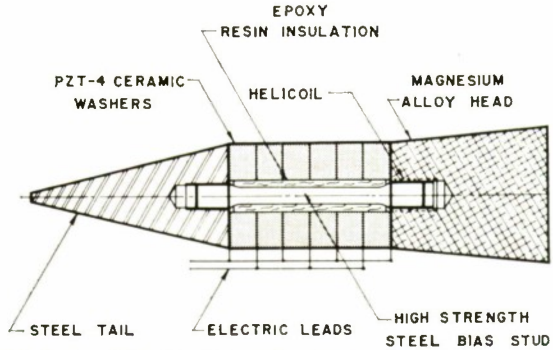

FIG. 5. A unidirectional conical projector which has radiation in the direction of the tail cancelled by destructive interference.

the pod shown in Fig. 4, utilizes an array of two planes of hydrophones which, by delays and subtraction, cancels all signals except those from the desired direction, regardless of the depth of submergence.

Fluid Mechanics

Canadian interest in hydrofoil craft began in 1919 when Alexander Graham Bell designed and built a hydrofoil craft with which he broke the world's record for speed over water on the Bras d'Or Lakes of Nova Scotia. In the early 1950's DRB acquired a 45 ft. hydrofoil craft fitted with surface piercing foils similar to those used by Bell in order to look further into the design of such craft for ASW purposes[6]. After model tests had been made by the Admiralty, a larger boat, now known as BADDECK, was built in England in 1957 to investigate the possibilities of operating hydrofoils under open ocean conditions. This craft, shown in Fig. 6, has now been fitted for high-speed towing. A 3-ton experimental craft, Rx (Fig. 7), with foil positions adjustable, was later constructed to test foil designs.

Based on work with these craft, NRE predicted in 1959 the feasibility of an operationally useful ASW hydrofoil ship, and these studies formed the starting point of the Canadian Forces' *FHE*-400 hydrofoil programme. This 200 ton ocean-going craft, to be known as HMCS BRAS D'OR, has been designed as an ASW escort vessel and should be capable of remaining at sea for long periods of time in the displacement mode and running at high speed on its foils when required to do so. One-quarter scale foil designs for this craft were tested on the versatile Rx and, with it, parameters of motion of a hydrofoil craft in the sea were obtained.

As an allied project, the problem of the design of towed bodies to give a variable depth sonar capability to such craft is being investigated. Two phases of this are under study. Fluid dynamicists are learning how to design bodies suitable for high

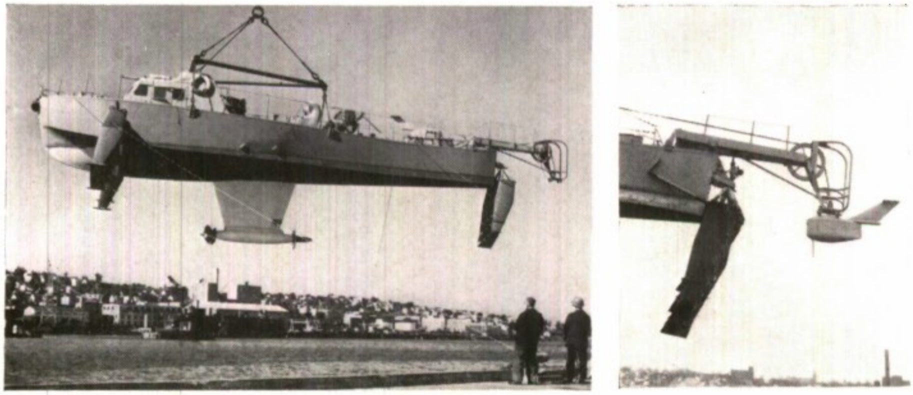

FIG. 6. Hydrofoil craft "Baddeck" (formerly "Bras D'Or") fitted for towing, with experimental towed body shown at right.

speed towing and as noted previously, acousticians are investigating the noise levels likely to be met in such a sonar application. Using the hydrofoil craft BADDECK as a foil-borne high speed towing vehicle, realistic tests of faired cable, and research on body design and noise levels are being carried out with instrumented towed bodies.

High Strength Materials Research

For several years NRE has been developing high-strength electro-deposited thin iron foils which can be bonded together to form a composite material with a high strength-to-weight ratio and other desirable properties such as good corrosion resistance and good fatigue life. Iron was chosen as the metal for study because of its relatively low cost, high intrinsic strength and variety of possible strengthening mechanisms. Phase I was completed in 1964 with the demonstration that tensile strength three to four times that of bulk material could be produced in foils 0·001 in. thick. Phase II, a detailed study to see how the properties of the foils depend on the characteristics of the plating bath, is in progress.

Direct Assistance to the Military

An Anti-Submarine Warfare Service Projects Unit was established in 1965 for the purpose of providing some direct scientific assistance to the Maritime Command Atlantic in its efforts to extend its ASW capability. It has been concerned with a number of projects, for the most part in the field of improvements to existing instrumentation. To date these projects have dealt with many aspects of explosive echo-ranging from aircraft, passive submarine detection devices for both ships and aircraft, and acoustic torpedo decoys. Service officers participate to a significant extent in the work of this unit.

The DREA's Dockyard Laboratory provides consultative advice to the Canadian Forces on various phases of ship construction, repair and maintenance, and on miscellaneous materials problems. Specialities are welding techniques and non-destructive testing of hulls and components by radiography and other means. The testing of oils and lubricants and investigations of corrosion problems are routine activities. About 25% of inquiries received relate to chemical analyses and paints. Application of its varied techniques to the detection of causes of failure of vital units, or the prevention of failure by discovery of defects, forms part of this laboratory's activity.

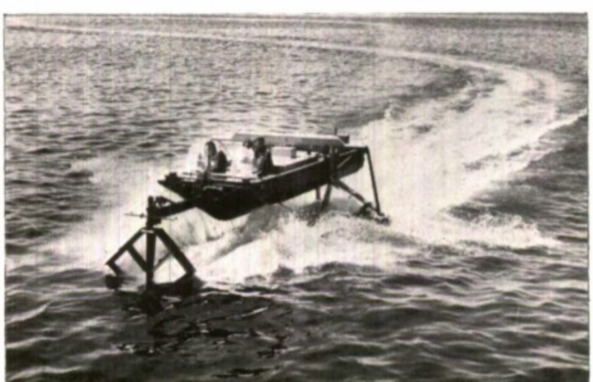

FIG. 7. Experimental hydrofoil craft Rx.

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RADIO INTERFERENCE PROBLEMS in the Royal Navy

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Introduction

This article is based on a paper presented at Portsmouth and Christchurch to the Southern Electronics Section of the I.E.E. during the first quarter of 1966. The treatment of the subject assumed that the audience has no knowledge of H.M. Ships and of the conditions under which the complex electrical and electronic systems at present fitted are expected to operate.

The subject which necessarily covers the whole range of naval electronics is limited in this paper by the difficulties involved in producing a logical and comprehensive treatment without jeopardising the Official Secrets Act and without mentioning specific equipments. It may not be generally realised that all naval equipments have type numbers, and when talking about a Type 467 interfering with a Type 32, a naval audience would immediately know that Type 467 was 10 watt VHF transmit/receive system, and that a Type 32 was an L2 band radar. These types are of course fictitious, but demonstrate, that when discussing specific interference problems involving specific naval equipments it would be necessary to spend considerable time describing equipment characteristics, which even if it was allowed would not impart much information about the overall interference problems in the Royal Navy. This paper will therefore be confined to the general causes of interference in H.M. Ships, as they affect operational equipments designed to receive and process information electronically.

The Problem

It would seem reasonable to start with the Interference problem, and to try and pass on some idea of the problem that exists in H.M. Ships, and then go on to describe a little of the organisation and techniques that have been, and are being evolved to combat this serious and persistent problem in the Royal Navy. Prior to this, a few definitions would be pertinent and a definition of radio interference in simple and general terms is a good starting point. Radio interference is any electronic or electrical phenomena which degrades, or obscures the intelligence of electronic communication. Within this context is included what can be defined as active communication, whereby exchange of information with other ships, aircraft and shore establishments takes place by the transmission and reception of voice or radio telegraph. Also included are passive detection methods such as radio direction finding, and active detection methods such as radar or sonar. The distribution of information within the ship, by audio lines, data transmission of position, and control by magslip and synchro systems; radar and sonar target data by video lines, and audio, is also included within the definition of electronic communication.

It is difficult to give examples on paper of interference to radio reception, but the effect must have been experienced by anyone who has listened to a radio or television with unsuppressed electrical machinery in the vicinity; how annoying at the time, that one's pleasure or interest has been destroyed by crackling, buzzing, screeching, *etc.*; how disastrous under circumstances when effective operation of a ship depends on clear reception of a vital message. Fig. 1 shows an example of radio communication interference, which could have had a serious effect on the operational efficiency of an aircraft carrier. The meteorological information essential to aircraft flying is transmitted and received over an HF link and automatically printed out; the black bands obscuring vital information was caused by the ship's own transmitters. Fig. 2 shows two typical examples of interference affecting radar presentations. The interference is caused by a second radar nearby, operating on or near the

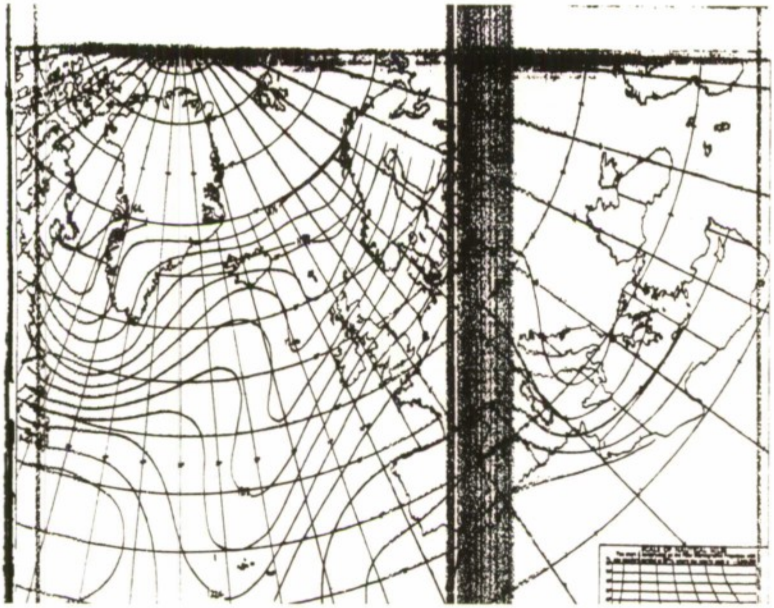


FIG. 1. Interference to meteorological report received on HF link

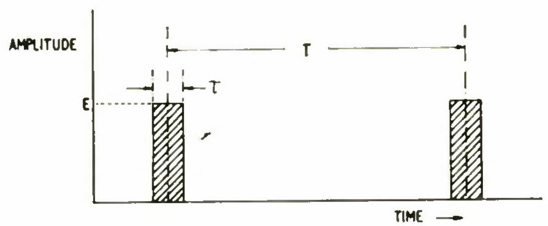
same frequency, or harmonically related to the radar frequency. By obscuring the required radar returns, information relating to enemy targets may be lost by reduction of first detection range; at worst, targets may be detected only as an attack occurs when due to an absence of information weapon systems are unprepared. Dependence on radar for navigation makes ships more susceptible to collision when echoes are indeterminate or lost due to displays being cluttered up with interference. The well known technique of hiding the position of one's ship by raising a smoke screen is useless against present day electronic detectors, and has been replaced by raising a lot of radio noise to saturate the radio and radar reception of enemy detectors. A stratagem known as jamming. It really is silly to raise so much radio noise in one's own ship that one's own radio and radar reception is effectively jammed, and the high potential performance of equipment, paid for in hard cash and manpower, is dramatically or insiduously reduced much more effectively than the enemy can do it, and at no cost to him. In practice, if one could jam the electronic equipment of an enemy as well as one sometimes does to one's own, the navies' operational tacticians would be highly delighted.

FIG. 2. Interference to radar presentation.

Transmitters and Receivers

In an interference sense, each piece of electrical or electronic equipment can be considered as a transmitter or a receiver of electromagnetic energy, most equipments in fact act as both. It is not necessary here to define equipment that is designed to transmit information at a particular frequency,

nor equipment that is designed to receive information at a particular frequency. The transmitters and receivers of particular interest are those equipments which generate and radiate frequencies they are not required to; and those equipments whose operation is affected by frequencies to which they are subjected, but not designed to withstand. All electrical or electronic equipments fall into both these categories. In general, conventional transmitters are less affected by interfering frequencies, unless the interference power is very high, or unless the transmitter modulation takes place at very low level. Such transmitters can however radiate frequencies they are not supposed to, and will do so unless the design techniques to minimise spurious radiation are applied. It is worth mentioning, that although such spurious radiations may not be harmonically related to the desired frequency, in general such a relationship does exist. As well as extra band radiation, transmitters do radiate broadband noise, usually at very low level, but sufficient at times to affect co-located receivers. This broadband noise is common to all electronic systems, and is generated in the components of the system, and amplified to appear at the output. Radiation from transmitters will occur not only from an associated aerial system but also from the cabinet and connecting cables unless adequate precautions are taken to prevent this. In a similar manner, it is obvious that any equipment which generates electrical power or information will act as a transmitter by radiation from the cabinet or from connecting cables; such radiation will be broadband noise or of a frequency spectrum related to frequencies internally generated.



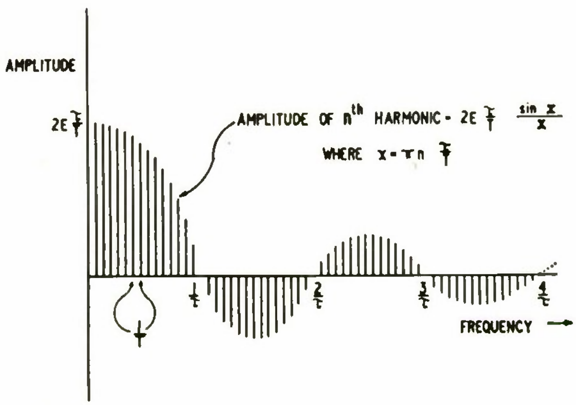


FIG. 3. Harmonic content of a rectangular pulse.

Consider the problems arising from the use of pulse generating equipments now that more and more of such equipments are being introduced into ships in the form of pulse radars, digital computers, data transmission systems, all of which depend on the generation and transmission of electrical pulses. Each of the pulses can be analysed, and it will then be seen that the spectrum consists of an infinite number of discrete frequencies. Fig. 3 shows the theoretical frequency spectrum of a rectangular pulse train; it is the sort of picture that appears in all text books on Fourier analysis, and is too often considered from a theoretical point of view only without realisation that each of the component frequencies can be radiated from a pulse generator source and affect receivers located within the range of influence. Fig. 4 shows the theoretical frequency spectrum obtained when a carrier of frequency f is pulse

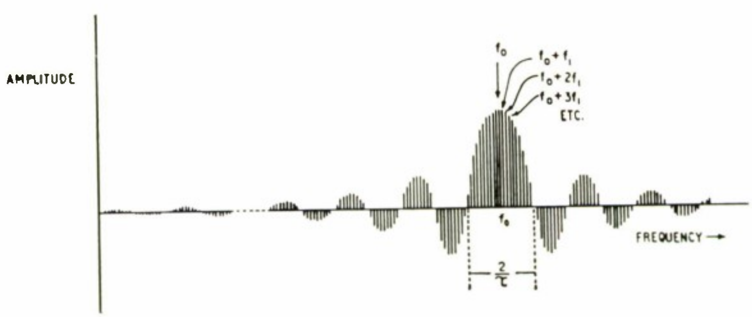


FIG. 4. Frequency spectrum of pulse-modulated radar.

Fundamental frequency $=f_0$ c s
Pulse repetition frequency $=f_1$ c s
Pulse length $=\tau$ secs

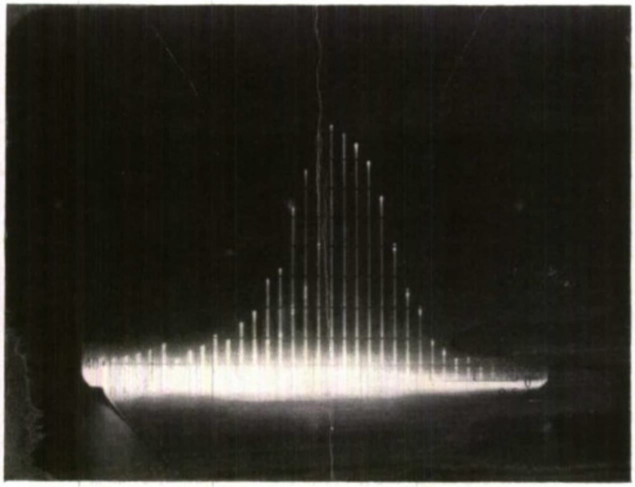


FIG. 5. Spectrum of a naval pulse modulated radar.

modulated as in a radar; in this case, the component frequencies extend at the pulse repetition frequency throughout the whole frequency range. Fig. 5 shows the spectrum of a naval pulse modulated radar which confirms the theory. The introduction of digital computers into H.M. ships has also caused problems. Fig. 6 shows the measured cabinet radiation from a computer at present fitted, the spurious radiations within the HF radio band are obviously above any satisfactory level. Five hundred kc/s as a working frequency was chosen without reference to any environmental requirement, since it is also the International Distress (Mayday) Frequency and should obviously remain inviolate in any complex which requires HF reception on that frequency. The higher harmonics at 4, 6 and 8 megacycles coincide with standard Frequency Shift Keying transmissions also used on the ships. On one of the remaining capital ships of the Royal Navy, equipment frequency planning has been such that the major surveillance radar has an Intermediate Frequency of 8 Mc/s, an HF aerial whip used for transmitting 0·5 kwatts of power at 4 and 8 Mc/s has been placed within 25 feet of the radar aerial containing the head amplifier and frequency converter. Each time HF transmissions are made the performance of the radar is degraded, because of an increase in the IF noise level.

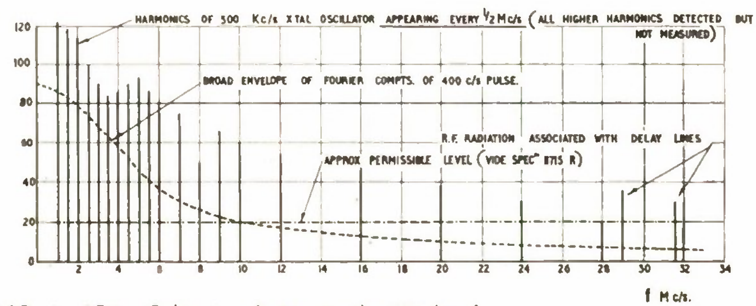


FIG. 6. ADA—Cabinet radiation in the HF band.

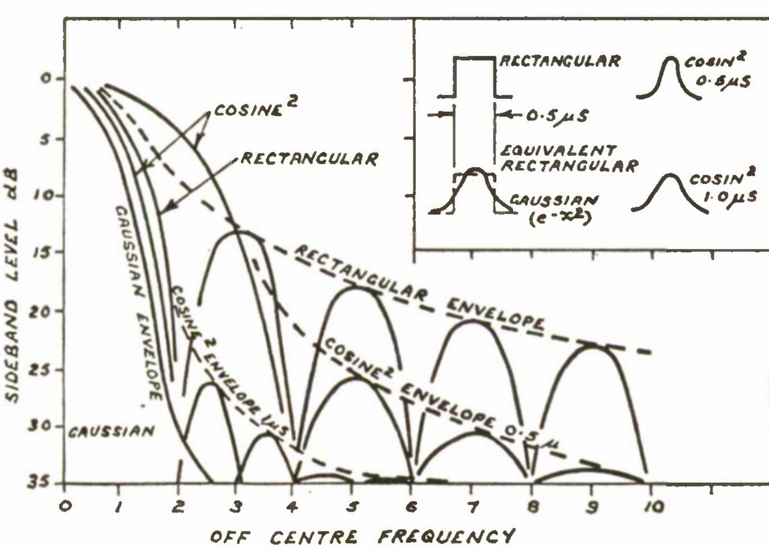


FIG. 7. Power spectrum curves.

Without too much elaboration it is worth mentioning the effect of pulse shape on the Fourier sideband frequencies; obviously the lower the sideband power transmitted, the less the interference potential of the pulse. The majority of pulse circuit engineers design for perfectly rectangular pulses with very sharp rise times, often when the rectangularity is not necessary for optimum system working, and often without realising that the faster the rise time the broader the pulse spectrum. Fig. 7 compares the frequency spectra envelopes of a number of pulses, and it is obvious that the rectangular pulse is by far the worst and that the gaussian pulse is the best. It has also been argued that sharp rise times are very often unnecessary, even in high definition fire control radars: in surveillance radars where the tar-

get position is determined by the integrated return of a number of pulses, very sharp rise times are definitely unnecessary. Observations during experiments have shown that reflections from non-uniform surfaces, such as those presented by an aircraft target, will distort the leading edges of transmitted pulses and much of the precise range information inherent in the sharp leading edges of the reflected pulses will have been destroyed. The requirement for pulse shape should be carefully considered at design stage, and in particular requirements for sharp rise times definitely justified; in all other cases the pulses should be as rounded as possible; the engineer will find plenty to exercise his talents in designing pulses having a cosine or gaussian envelope.

Before leaving the subject of transmitters it is worth mentioning inter-modulation products caused by "rusty bolt" effects. In a ship's superstructure, built of steel and aluminium and other metals, a very large number of electrical non-linear junctions are formed by corrosion and rust between contacting parts of the superstructure. When these non-linear junctions, having a complex semi conductor non-ohmic characteristic, are subjected to high power radiation from a number of transmitters, they are capable of retransmitting power at the sum and difference frequencies known as intermodulation products. Thus, if a non-linear junction is subjected to frequencies f_1, f_2, f_3, *etc.* then frequencies of the form $af_n \pm bf_p \pm cf_q \pm \ldots$ where (a b c . . . ., n p q . . . . is any integer from 0 to infinity) can be reradiated. It can be shown that with six transmitters the fifth order intermodulation products (of the form for example $2f_1 + f_3 + 2f_6$) formed will run into tens of thousands, each of which can affect a receiver aerial in the vicinity.

When a receiver is energised, and tuned to the required signal frequency it is often imagined that transmissions at other frequencies will have no effect. Fig. 8 which shows the response of a typical receiver tells a different story; as well as the nominal receiver response, a number of other responses exist in the input/output characteristics, each of which is energised by inputs at the response frequencies, and which appear at the output, obscuring the required signal. These spurious responses except for the image response which is a local oscillator effect, are present in the input circuits and are caused by the parasitic or transient tuned circuits formed by stray capacitance and inductances in the manufacture of the receiver. In Fig. 8, superimposed on the response curve is the frequency spectrum of a narrow pulse, showing that each component of the receiver response coincides with one or more of the pulse spectral frequencies, each of which will affect and degrade the output of the receiver.

Although the remarks above have been generally concerned with conventional transmitters and receivers, it must be repeated that any electronic instrument or equipment whose purpose it is to process electrical information to produce a useful output can be considered as a transmitter and a receiver; if it radiates energy that is not necessary to its functioning or purpose or if it is affected by electrical or electronic emissions it has not been designed to withstand. Thus, for example, the servo amplifiers controlling a gun director may well receive energy from HF or radar transmissions on the same ship, causing the gun to follow the orders intended for it in an erratic manner. A digital computer controlling the weapons systems of a ship may be affected by power supply transients or radar transmissions.

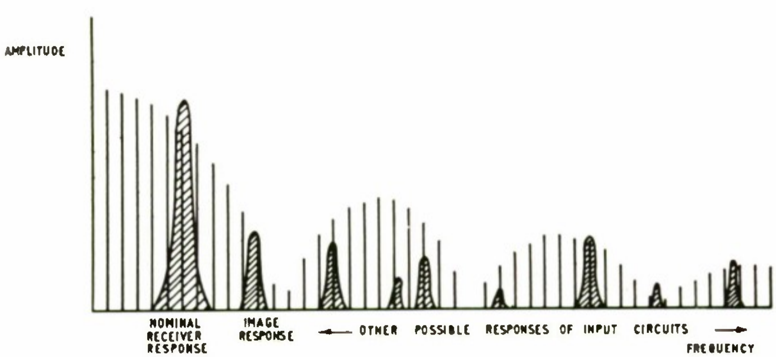


FIG. 8. Mechanism of short-pulse interference to a typical receiver.

Historical Note

Before the 1939-1945 war, ships were concerned with interference problems associated with MF/HF communications, and when in major war vessels of 25,000 to 35,000 tons the number of transmitters was increased to six and the number of receivers to eight, the mutual interference was considered serious. After much deliberation at high scientific level certain rules were formulated and applied to these ships. Transmitter offices were placed near the foremast, receiver offices near the main mast, transmitter aerials were rigged from the foremast and receiver aerials from the main mast, mast structures were arranged between the aerials and 100 feet separation demanded between transmitter and receiver aerials. Transmitter and receiver characteristics were specified in order that the equipments were mutually operable.

With the war and the advent of radar, which naturally had top priority in ship fitting, and took the cream of available scientific effort, many of these precautions were forgotten or ignored, and progress in the development of mutually compatible systems and improvement in interference prevention became a steady degradation which is now being fought. Imagine the situation today, where the transmitter and receiver facilities have quadrupled: sonar, passive detection, automatic data handling equipment, radar for surveillance, navigation, gunnery, and missile control has been added to a ship approximately one fifth of the size of the pre-war vessel.

FIG. 9. A typical aerial Configuration circa 1959.

Prior to 1939 in a major war vessel there were:

6 transmitters for MF/HF
8 receivers for MF/HF

In a present day operational ship there are:

16 transmitters for MF/HF/UHF
30 receivers
10 radar transmitters
12 radar receivers
and a computer.

In future there will be:

21 transmitters for MF/HF/UHF
34 receivers
6 radars
and a computer.

Six radars rather than 10 does not mean any reduction in the power or frequency handling capacity of the ship; conversely it involves a considerable increase over the present day ship.

With the increase in equipments and reduction in ship size, the 100 feet aerial separation demanded for pre-war ships is impossible to apply, and one is lucky if 100 inches can be maintained between all the aerial systems required above the deck of a ship. Fig. 9 shows a typical aerial configuration of eight years ago and the situation has not improved. MF/HF/UHF/SHF aerials radiating and receiving within inches of each other.

To summarise; since 1939, the size in ships has reduced by five times, ignoring aircraft carriers, since the Royal Navy is now mainly a small ship navy, and in broad terms it can be said that as much electronics goes into a modern 5,000 ton ship as into a 35,000 ton carrier. The transmitter power capacity has gone up at least a thousand fold, from five times as much transmitter equipment; the frequency requirements have increased down to VLF and upwards to kilomegacycles, receiver sensitivities are increased 10 times. Radar, wideband passive location equipment, sonars, computers and exceedingly complex and sensitive data processing equipment have been introduced; and there was a problem before 1939. Now, remembering that it has taken five to ten years to bring a major equipment project to the state where it is operational in a ship; particularly where a new class of ship is involved, it is worth emphasising that with the re-equipping of the Navy after the war, the major research and development effort was aimed at producing equipment to meet stringent performance requirements, to keep up

with the rapidly increasing technological advances available to potentially hostile navies. Radio interference suppression was relegated to a back seat; all effort in this field was aimed at keeping existing ships and equipment working, on the assumption that, when the new equipments would be fitted there would be no interference. Major ship system and installation decisions were taken without reference to potential interference problems engendered by such decisions. However, after some of the new, sophisticated, and very expensive equipments had been installed in ships and found to be incompatible with their environment (which is only a euphemistic way of saying that they did not work where they were supposed to) a realisation that radio interference suppression techniques was an active important subject, applicable to all stages of equipment development, production, and installation, was forced upon the equipment and ship building authorities. In the United States of America, the Defence Authorities became aware of the radio interference problem at about the same time and philosophised that, "it is ridiculous to produce and develop large, expensive, complex equipment to severe performance requirements; to find, that when they are fitted into the environment for which they were intended they are incapable of performing, because we had failed to apply what would have been a ridiculously small proportion of the overall effort to the problem of interference reduction." It is fair to say, that today in the Royal Navy, the danger of this oversight is clearly evident, and that a growing awareness of radio interference at all levels in the M.O.D.(N) organisation, from the Staff Divisions, through the design groups and dockyards, to the working ship level, is going a long way to ensuring that our electronic equipments are no longer subject to the severe interference problems which became apparent five or six years ago. Radio interference is like cancer, and continuous vigilance is the price of efficiency and effectiveness, this growing awareness needs nurturing and sustaining, because radio interference suppression techniques involve money, time and effort, all commodities on short supply, with many contenders for available resources. At design level, equipment specifications have interference susceptibility clauses deleted in the interests of false economy and improved performance requirements; made nonsense, because any potential performance improvements are often nullified by interference effects. At installation level, techniques are omitted through ignorance of the reasons for the requirement. At ship level interference trials and maintenance procedures are omitted, because they are either too much trouble or because there is something else more interesting to do. At all levels there is a lack of understanding.

Ship Problems

The Royal Navy is ships and men, and it is perhaps a little remiss to have arrived so late in a paper about interference problems in the Royal Navy without giving specific reasons, why electromagnetic interference can be, and is, such a problem. After all, it can be reasonably assumed, that no matter how many electrical systems are fitted in a ship; provided they are correctly designed and installed, they should be able to work together at the same time. What then are the reasons why such systems which when set to work alone and ashore can and do operate as required; yet when installed on board one of H.M. ships render others or are themselves rendered impotent ? The answer to this must lie in the meaning of correctly installed. Correct installation of an individual equipment is not sufficient to ensure complete operational availability and flexibility, when it is installed in close proximity to, intermingled with, and interlinked in intentional and unintentional ways with other equipments and systems. As a simple example, one can consider the acoustic circuits interlinking each operational and manned compartment, via microphones, loudspeakers and amplifiers. It is not difficult to imagine the effect of placing a microphone in close proximity to an audio noise source: or to a loudspeaker on the same system, so forming an acoustic feedback loop such that the whole system goes into oscillation; in both cases every compartment containing a loudspeaker will be filled with so much noise that voice communication will be impossible. Under some circumstances the noise level or pitch can be so high that it causes physical pain to any occupants and the compartment becomes untenable. Under correct operational conditions the communication system is unobtrusive and unnoticeable until required for passing the essentials of a message. In a similar way electronic systems can generate electrical noise or distribute it about the ship, degrading the performance of related and unrelated equipments.

The purpose of radio interference suppression is to separate those electrical signals which are mutually detrimental, and all the techniques available can be broadly classified under two headings, filtering or screening. Filtering techniques accept that the interfering and required signals are mixed and it is necessary to remove the interfering signal. Screening techniques accept that the interfering and required signals are present but separate, and it is necessary to ensure that they stay separated. If it is possible to ensure that all potentially interfering signals are kept separate from all information carrying signals the interference problem is solved and all equipments and systems will operate as intended. Difficulties arise

in applying these techniques because, with increasing complexity it soon becomes impracticable to predict all potential interfering signals and their effect; even if such prediction is possible it is not always practical to apply the necessary prevention techniques to guarantee a complete interference free environment without increasing the size of the ship, and imposing a disproportionate burden on the equipment and system engineers and the ship builder. The solution must be reduced to a study of the most susceptible areas and applying the simplest and most effective palliatives.

For the purpose of this paper it is convenient to divide the ship into three broad sections and consider each separately. The three divisions made are very obvious; that section outside the hull; in particular, above decks; those compartments inside the ship which contain electronic signal processing equipment, and finally, those gangways, passageways and ducts which carry the cables inter-connecting the compartments.

Above Decks

Situated above decks are those electronic elements which enable the ship systems to communicate with the outside world, that is the transmitting and receiving aerial systems. The methods available to prevent interaction between aerials are separation, screening or filtering. On present day ships, effective separation is impossible because of the number of aerial systems fitted, and the relatively small area available. Screening is generally unacceptable because of all round operational requirements for most systems; if any unavoidable screening occurs due to the juxtaposition of ships superstructure and aerial, the fitting of second elements to overcome any operational limitations is always considered. Operationally increased versatility and flexibility are required and the trend is to make aerials as wideband as possible, so that filtering, in the sense that a narrow frequency band device is utilised, is not considered as a very suitable solution. Tuneable filters installed at aerial sites is only a suitable solution when limited frequency flexibility is required, for example on altering a fixed radar frequency by changing a magnetron. In most other cases, where frequency flexibility is required filtering is cumbersome and generally unsatisfactory due to the complexities of remote tuning and the susceptibility of the signal cable, between the aerial filter and the equipment unprotected by the filter. Such filtering is best applied at the equipment input, and above decks interference induced into aerial receiving system cables most effectively removed at the equipment. Other potential interference carriers are general power supply cables and braided cable screens and these cables should be treated in such a way that the interference is not conducted to sensitive areas. Inside the ship this means that ideally all supply cable cores should be filtered and all braids should be bonded to the ship's weather deck where such cables or braids enter the ship. A moment's thought will immediately show the difficulties of applying such a solution, great practical difficulties exist in producing effective interference filtering to cover all the power carrying requirements and the incorporation of such filters into the ship, bearing in mind that each cable core has to be separately treated. Similar difficulties apply to the bonding of cable braids at the weather deck without damaging the cables, in all cases the watertight integrity of the ship must be maintained. Even if such special glands and methods of treatment were available the expense of incorporating them would be enormous, and more to the point, in 99 cases out of a 100 such treatment would be unrewarding. Of the "above decks" problems a number of solutions are being considered, and one hopes that practical, effective and economically viable methods of suppression will soon be available.

Equipment Compartments

It is not my intention to spend very long considering the electronic equipment compartments, it will suffice to consider the problems and the general solutions which are now being applied in the most modern ships. Every compartment in a ship constructed of steel or aluminium and with unpierced bulkheads and a well fitting door, demonstrates a practically unmeasurable electro magnetic field screening attenuation. If equipment situated within such a compartment was powered by self contained batteries, no cables or wires entered or left the compartment and the door remained shut, this screening attenuation would remain as high, but such a compartment is operationally useless because no effective communication exists between it and the rest of the ship. If however one simple cable only is passed through the bulkhead and is fed around the ship, it acts as an aerial to all the interference fields present and all the possible attenuation gained from the bulkhead material and continuity can be lost and the compartment is electrically open to all the electromagnetic sources which can affect the cable. All the electronic equipment compartments in the ships of the Royal Navy have numerous cables of all sorts, types and sizes, carrying all sorts of currents, frequencies and signals passing to and fro through their bulkheads. Very often these cables passing through such compartments have nothing whatever to do with the equipment which is installed within the compartment. Thus it has been found (and measured) that higher inter-

ference field strengths exist within Radio Receiving offices than anywhere else in the ship, even in the open air above decks. In such ships the electromagnetically quietest area has often been found in the Wardroom, where no cables (except for lighting and telephone *etc.*) were to be found.

Techniques of filtering, screening and separation of cables, which were considered in the "above decks" case also apply to compartments and we can generalise by stating that for a compartment containing sensitive electronic equipment

(a) No cables, wires *etc.* other than those required for equipment contained within the compartment are to be routed through the compartment. If such routing is unavoidable such cables are to be trunked in an electrically continuous metal duct or trunk contiguous with the bulkhead.

(b) All other cables entering or leaving the compartment are to be screened, such screens to be bonded to the bulkhead, or if unscreened the cables are to be filtered at the bulkhead.

(c) The bulkhead of such compartments must be continuous.

Compartments in ships are divided into three groups depending on the equipment inside. In the first group no interference precautions are fitted, except under specific circumstances relating to the equipment when main power supplies are filtered. In the second group, limited precautions are taken, which amount to the fitting of main power supply filters, and ensuring that only cables associated with the compartment equipment enter or leave the compartment. The third group of compartments contain the sensitive electronic equipment usually associated with radio reception, and these compartments are fully screened and suppressed. Where ideally, all cables entering or leaving the compartment are screened or filtered, no unrequired cables are allowed in, bulkhead continuity is maintained, a screened door which when closed is electrically continuous with the bulkhead is fitted. Naturally there are exceptions to the cables entering such compartments; these are usually the signal cables carrying the information requiring processing in the equipment inside the compartment. The interference suppression required for such cables is usually contained with the signal processing system.

It is not necessary to say any more at this stage about ship compartments except to utter a warning about jury-rigging suppressed compartments for trials or equipment modification purposes. It is not unknown for cables to be fed into radio offices for various clandestine though justifiable reasons thus degrading the ship's radio reception and equipment performance.

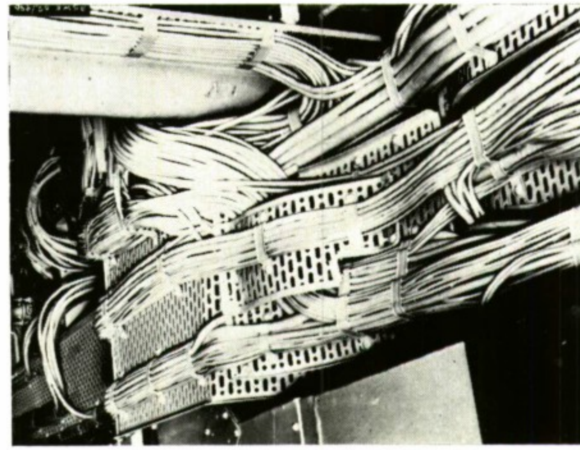


FIG. 10.

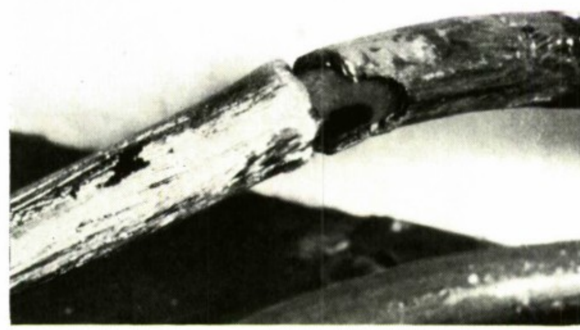


FIG. 11. Example of break in a lead cable sheath.

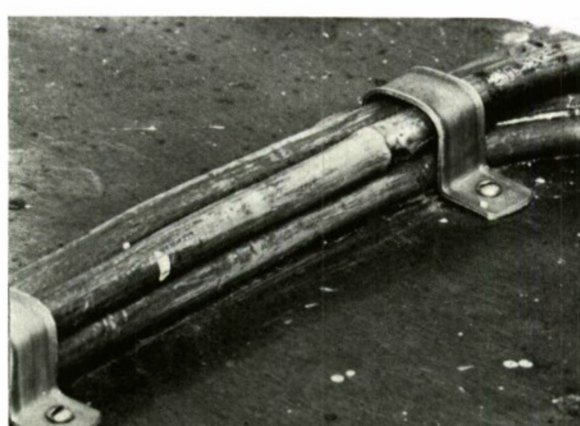


FIG. 12. Another typical break in a lead cable sheath.

Interconnecting Passageways

Having dealt in a very superficial way with " above decks " and compartment problems it has led to the last ship section that will be considered; interconnecting cables, passages and ducts.

Throughout each naval warship an immense number of cables and wires interconnect each and every office and compartment carrying electrical power supplies for lighting, heating and equipment; other cables carry signal data and electronic information of all power and frequency levels to and from equipments.

The main interference problem associated with cables in cable runs is to prevent the transfer of electromagnetic energy from one cable to another; this transfer of energy is due to mutual or cross-coupling between the cables, and the higher the cross-coupling attenuation between cables, the smaller the energy transfer.

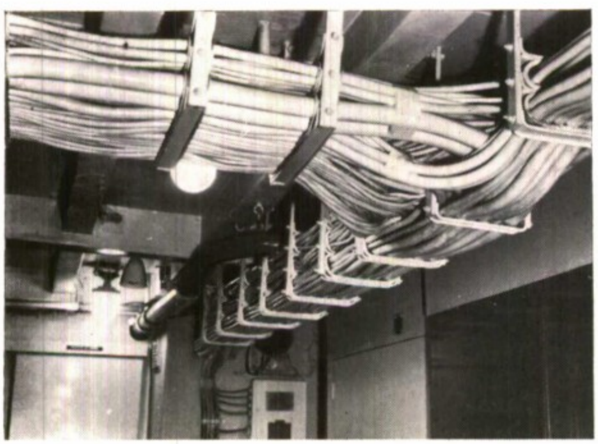


FIG. 13. Present-day technique.

In the past all cables running through a ship were solid sheathed in lead or copper, and were clipped back at frequent intervals to a metal channel plate; both of which resulted in a large amount of cross-coupling attenuation between cables. The system is shown in Fig. 10. Lead cable sheaths are however mechanically weak and liable to fracture, either at installation due to mis-handling or because of metal fatigue caused under normal ship vibration or shock conditions over a long period. Figs. 11 and 12 show two examples of breaks in lead cable sheaths. Although cable sheath fractures can render the effective screening useless at the fracture, because of grounding at regular intervals along the cable length and the high overall degree of inherent screening protection available this does not usually matter, except in the case of low level coaxial signal cables where the lead sheath is used as a signal return path. The second advantage in this system can be summed up by stating that the electrical energy induced into a cable or screen by an electromagnetic field is proportional to the field strength and the loop area formed by the cable or screen and (in this case) the earthed channel plate. By earthing the cable sheath at regular close intervals, and by clamping the cable tightly to the channel plate any loop formed is minimised, and induced interference currents kept to a minimum.

Compare this with the present day technique shown in Fig. 13, where in general unsheathed cables are used supported in cables hangars, a sort of inverted croquet hoop hung from the deck head. Specified cables will of course be screened, either in metal braid or less frequently in a solid metal sheath. Considering again the two aspects previously discussed, all general purpose cables are unscreened giving rise to far greater potential interference from stronger radiating fields. Sensitive cables are screened in metal braid which gives far less protection from interference than solid metal sheaths particularly at higher frequencies. The cable hanger system creates a large effective loop between the cable and the effective earth plane of the deck head; thus, interfering fields which are larger due to poorer screening induce higher interference currents into sensitive cables made more sensitive to interference by a larger loop. In view of what I have just written in criticism of the cable hanger system, why is it used ? The simple and effective answer in this era of cost effective decision is, for economic reasons. Obviously, looking at the relevant Figs. 10 and 13 there is much to commend the cable hanger system: simplicity of installation, cheapness of materials, ease of modification all with consequent saving of money and man power. As a result, another solution must be found to a worsened cross-coupling attenuation between cables with consequent deteriorating interference problem, engendered by the introduction of a cable hanger system.

One solution is to separate cables which carry mutually incompatible signal powers, because electromagnetic field strengths diminish fairly rapidly with distance particularly in the near field, and any physical separation increases the cross-coupling attenuation. A moment's diversion to state, without proof and in its simplest form, near field radiation. Any point in space, a distance r from a simple Electric Dipole (a high impedance source) or a simple Magnetic Doublet (a low impedance source) has six associated fields, three magnetic and three electric. In each case, three of the fields are of zero value, and the three others have values proportional to terms in $1/r$, $1/r^2$ and $1/r^3$. When $r=1/b$ the terms become equal in magnitude; b=the free space phase constant$=2\pi$ f/c (f

=frequency of radiating field and c=velocity of electromagnetic waves in free space). When r is very much less than 1/b; only the 1/r term is significant, and the field intensity so defined, which decreases rapidly with distance, is known as the near or induction field. When r is very much greater than 1/b, only the $1/r^3$ term is significant and the field intensity so defined is known as the far or radiation field. (In considering the power flow at the point in space, as defined by the Poynting Vector the average real power is in the radial direction and varies as $1/r^2$.) From this it follows, that if cables can be mutually separated, a considerable reduction in cross-coupling results. However there is a limit to separation, which is reached so quickly in practical ship-building that the technique seems almost non-existent, although if we take worst case cables and treat these in isolation then a practical improvement of considerable importance is gained. The two worst case cables are the sensitive susceptible low level receiver aerial feeder cables, and the high power transmitter, C.W. and pulse feeder cables. In both cases the cables are sheathed in solid metal, usually lead, but can be aluminium or copper; receiver aerial feeder cables are separated from all other cables by a minimum of six inches; and the transmitter feeder cables are separated from all other cables by a minimum of 12 inches. No other cables are generally treated in such a manner, except where specifically requested and justified by the equipment or system engineer. Forceful arguments have been made against such a technique, usually on the ground that common earth coupling paths have a mutual effect much greater than any radiated field coupling. Such arguments are valid if the common earth coupling is large, which occurs in any cases where interference source and susceptible receiver are co-located. In many ship instances, the equipments are physically remote and since only the long main cables runs bring systems into close coupling, this coupling can be reduced by cable separation.

Coaxial Cables and Surface Transfer Impedance

The change from all cables having solid metal sheaths to a mixture of no sheathing, braided sheathing and solid metal sheathing has meant a much closer study of the effective protection to cables that braids and other techniques offer. The study of the screening effectiveness of cable sheaths has been tackled in two ways. Firstly, by laying cables in an earth system and measuring the mutual coupling between them. This has been done for a number of cables and for different braid earthing arrangements and has given an indication of the relative merits of the screening effectiveness of braids and the influence of an earth plane. The difficulty with using measurements of this type to predict what will happen in a practical ship environment is that any system built up in the laboratory is dependent on the specific characteristics of the laboratory system; and it may be foolhardy to extrapolate results very far. The main interest in the method must be to give a sense or feel of cable selection problems to an experimenter, or more practically, if a near representation of the required ship system can be built up, cable selection for a specific purpose is made more scientific.

The second method for measuring the screening effectiveness of braids is by means of a device known as a Triaxial Tester. This device shown schematically in Fig. 14 is essentially a heavy copper tube approximately 14 in. long × 2 in. diameter and forms the outer or triaxial screen for a coaxial cable sample. The coaxial cable to be

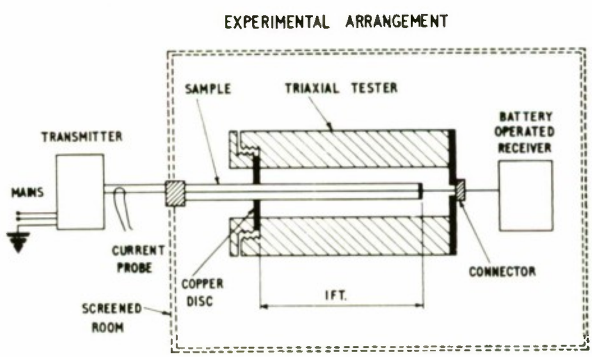


FIG. 14. The triaxial tester.

tested is made into a sample by soldering or welding a copper disc at one end between the cable sheath and the centre conductor. Twelve inches away from the shorted end a copper disc is soldered or welded to the cable sheath. This disc is clamped firmly into one end of the triaxial tester. A wire connection is made to the shorted end and fed out to a receiver, and a transmitter source of power is connected to the input of the cable sample between the centre conductor and the sheath. When this arrangement has been set up we measure the voltage developed along the outside of the cable sample sheath for a given current along the centre conductor, at a given frequency. More explicitly put, by measuring the voltage on the outside of a cable screen we can find how leaky the cable screen is

$$\left|Z_T\right| f = \frac{V_s}{Icl}$$

Where Z_T = Surface Transfer Impedance at frequency f.
V_s = Voltage measured along the screen.
I_c = Current in centre conductor.
l = Length of cable sample.

By measuring the quantity, known as the Surface Transfer Impedance, we are measuring a cable parameter, which is independent of external environmental conditions, and in this way it is possible to say that in any given cable configuration one cable screen will give better screening than another. It will also enable us in future to specify more precisely cable braid characteristics to cable manufacturers in the hope that we will be able to obtain cables with improved screening characteristics.

Most of our work has been concentrated on measuring the Surface Transfer Impedance of solid sheathed cables and some surprising conclusions have been reached.

Consider the expression of Surface Transfer Impedance of solid sheathed coaxial cables.

$$Z_T = \frac{Rox}{\sqrt{\cosh x - \cos x}}$$

$$= \frac{Ro}{\sqrt{1 + \frac{2x^4}{\lfloor 6} + \frac{2x^8}{\lfloor 10} + \frac{2x^{12}}{\lfloor 14} + \ldots}}$$

where $x = 2t\sqrt{\frac{\pi\,\mu o \mu r\, f}{\rho}}$

Ro = D.C. resistance of the sample sheath.

t = sheath thickness.

$\mu o \mu r$ = relative permeabilities of free space and sample sheath material.

f = frequency.

ρ = resistivity of sample sheath material.

The lower the Surface Transfer Impedance value the better the effective screening. The three main fields associated with a current carrying conductor are the circumferential H field, the radial E and the longitudinal E fields, and in a coaxial configuration they are inter-related and the triaxial measurement is of the longitudinal E field. In the coaxial configuration we have constrained the fields to follow precisely defined mathematical laws and are not, inside the cable structure concerned with near or far field effects. With these limitations it is obvious from the equation and from Fig. 15 (which shows theoretically predicted curves for Z_T of steel and copper sheaths) that up to a frequency which depends on the sheath thickness and the material characteristics the screening effectiveness depends only on the dc resistance of the material. Thus at low frequencies, a copper sheath is better than an iron or steel sheath and permeability effects are second order. Over some limited frequency range usually in the kilocycle range the iron or steel is better than the copper, then as the frequency increases the copper is better than iron or steel. As the frequency increases the permeability of the iron or steel falls, and at a faster rate of change than was first imagined, the curve for steel flattens off and it is believed will eventually rise with increasing frequency. Fig. 16 shows experimental curves measured on the laboratory equipment. The " common sense " advice that at low frequencies always use steel or iron is exploded, at least for screening in a coaxial configuration. It can also be shown that the same applies in the case of screening materials generally, and that the best screening would be gained from a copper clad high permeability steel.

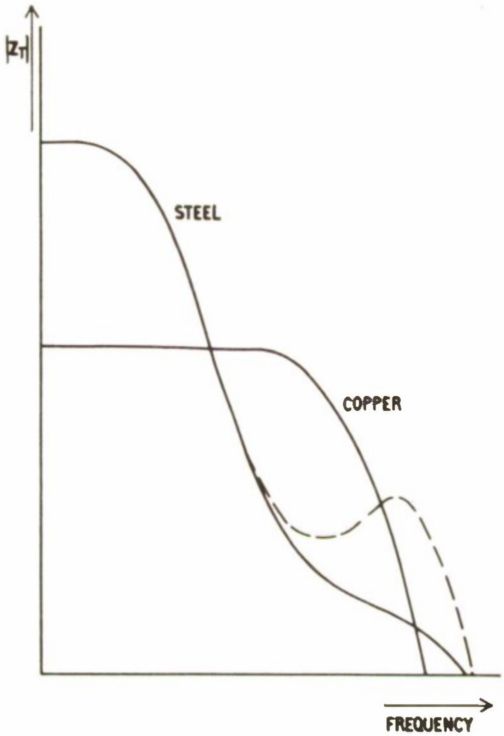


FIG. 15. Theoretically predicted curves.

One practical gain from our laboratory work was in enabling a choice of cable type for the replacement MF/HF receiver aerial feeder to be made on screening effectiveness grounds alone. In Fig. 17 when comparing two convoluted copper sheathed cables and the replaced lead sheathed cable, the BICC copper sheathed cable became

the obvious choice. If the other copper cable had been chosen the screening effectiveness of the aerial system would have been degraded.

A quick mention about braided sheathed coaxial cables, and referring to Fig. 18 where a comparison is made between the Transfer Impedances of Uniradio 70 coaxial cables sheathed in convoluted copper and in braided copper. Over the first part of the frequency range (up to about 0·5 Mc/s) the D.C. resistances of the sheaths are dominant and the curves are horizontal (the difference in levels is a measure of the difference in D.C. resistances of the two cable sheaths). At some frequency (0·5 Mc/s) the Surface Transfer Impedance of the braid reduces and as in the case of the solid sheath the curve starts to fall. At a higher frequency (3 Mc/s) this trend stops and the Surface Transfer Impedance increases rapidly with frequency; at this point the Surface Transfer Impedance equation no longer applies and a second mechanism due to an effective increase in the braid impedance takes over. I believe this is due to the current flow on the inner surface of the braid being resistively transferred from one braid thread to another at the braid thread cross over points and appearing at the outer surface of the sheath. At some much higher frequency a third mechanism takes over whereby radiated leakage takes place between the braid interstices, each of which acts as a small radiating slot. At frequencies where this occurs the cable acts as a radiating aerial and cable length becomes important. All available evidence shows that the Surface Transfer Impedance of braids continues upwards with frequency, and in the Kilo-megacycle range reaching ohms/metre, is comparable with the characteristic impedance for the cable. Pioneer work on screening effects of coaxial cables has been done by Krugel in Germany, in the U.S.A. by many workers, especially Ikrath and in this country by D. Harrison of U.K.A.E.A.

Just before leaving braided cables a word about double braids. Two braids in contact are generally better than one braid by 6 dB, that is twice the copper content twice the screening effectiveness, however at higher frequencies, power transfer from one braid to the next gives rise to resonance effects and at particular frequencies (dependent on the cable) the screening effectiveness may be much better or much worse than a single braid. Two braids with an insulated intersheath are no better than two braids in contact unless the inter-sheath is very lossy, in which case experimental evidence points to the surface transfer impedance being similar to that of a solid sheathed cable, at least in the HF band, it may rise at higher frequencies.

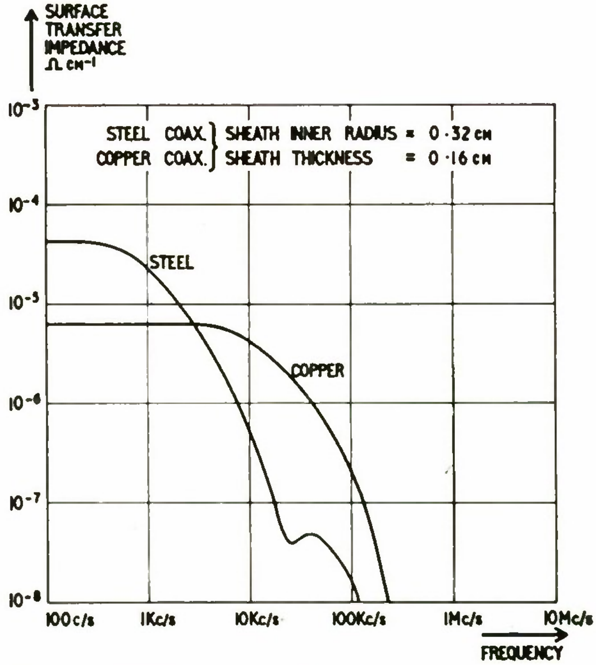


FIG. 16. Experimental curves obtained with laboratory equipment.

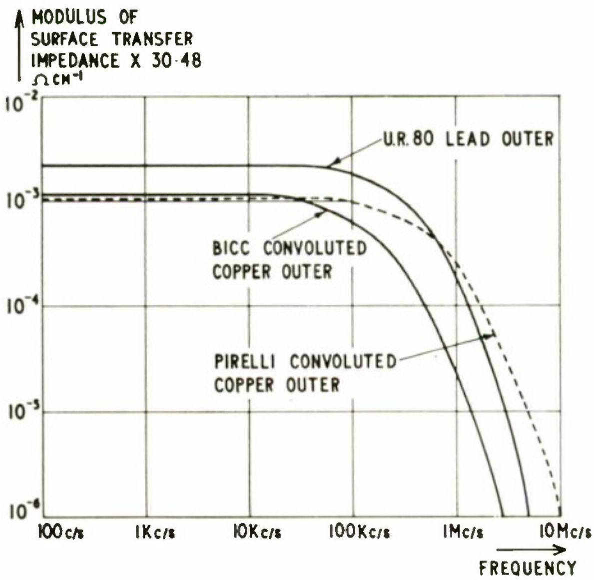


FIG. 17. Comparison of UR80, BICC and Pirelli cables.

It may seem strange to many readers to leave a discourse on cables without discussing twisted pair configurations. I intend to do just this, excusing myself with only two points, first the theoretical and practical work on twisted pair and triples has been extensively if not exhaustively covered by many workers, starting as usual with Schelkunoff's pioneer work. The second point I will make is that by twisting the conductors of a cable pair a very high degree of attenuation against electromagnetic fields is attained, the actual attenuation depending on the impedance balance between each line to all other elements in the system and on the line and configuration. In most practical cases the twisted pair is limited to frequencies below 100 Kc/s because of the difficulties of attaining a good wideband impedance balance. Such cables are extensively used for lower frequencies, but could be more widely used for power supply lines.

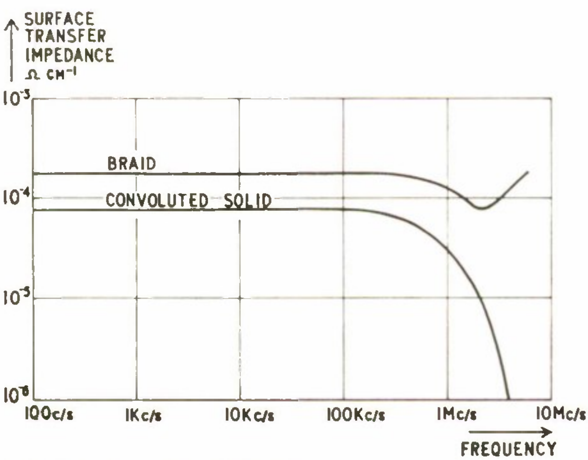


FIG. 18. Comparison of transfer impedances of Uniradio 70 coaxial cables.

Earthing

The big advantage in using a double braided cable with an insulating inter-sheath arises from the earthing arrangements which can be made when installing such a cable. Let me be quite honest here and state that there are no easy general rules that can be applied to earthing that will always ensure an optimum interference immunity irrespective of the installation. Such rules as I intimate here, though empirical, are based on scientific considerations which will become obvious as the argument proceeds. Though the argument will refer to coaxial cables the principles are in fact generally applicable.

A coaxial cable is a transmission line and subject to precise laws and mathematical treatment, because the voltages/currents and frequencies which are carried by the cable are constrained to follow known relationships. Such a cable can be confidently used by all engineers with little or no knowledge of Maxwell's Equations, and only a vague idea of Standing Wave Ratios and Impedance Matching. With this knowledge it is possible to understand earthing principles, even if the final applications only lead to an approximate answer. Consider a coaxial cable in relation to the earth plane configuration which forms part of the cable signal circuit due to mutual coupling (resistive, capacitive, inductive) between the cable and the earth. If we consider the circuit formed by the cable screen and the earth plane as a transmission line; and subject to transmission line laws the usual generalisations about single, double and multiple point earth systems all become understandable. Naturally, the transmission line so formed is complex, lossy, variable along its length and dependent on the earth plane configuration.

In general, a cable sheath earthed at both ends (a cable braid with multiple earths can be considered as a number of shorter lengths earthed at both ends) has a high susceptibility at low frequencies, falling at 6 dB's per octave as the frequency increases, to a null, where the cable length is equivalent to a quarter wavelength (not the same as a quarter wavelength in free space), rising again at 6 dB's per octave to a peak susceptibility where the cable length is equivalent to a half wavelength; this process continues with increasing frequency, producing a succession of nulls and peaks. A cable sheath earthed at one end has a distributed capacity to earth which forms a frequency dependent impedance, such a cable exhibits converse characteristics having a low susceptibility to low frequencies rising to a peak susceptibility where the cable length is equivalent to a quarter wavelength, falling to a half wavelength and so on. The dynamic range between the peaks and nulls can be as great at 140 dB. If the effect of a cable in an earth plane is considered in this way, the obvious way to reduce the interference susceptibility of the cable is to match the cable braid/earth plane impedance; this will eliminate the peaks and nulls. Such impedance matching is possible although we have had no experience of it, and it will be an empirical exercise carried out on site, although the necessary arrangements will have to be designed into the cable installation.

The other method of reducing potential interference, particularly with narrow band equipment is to ensure that the cable length used is

such that the equipment pass band corresponds to a susceptibility curve null. This is not as easy to do as to say, particularly where an equipment may be installed in multitudinous different arrangements and no single cable length is practically possible, the earth plane configuration will change from installation to installation so the susceptibility curve will differ from installation to installation. With this reasoning in mind and when braided cables are to be used we always recommend the use of a double braided cable with an insulating intersheath, in a single point earth configuration for the inner braid and a multiple point earth configuration for the outer braid. For what reasons is this the best compromise ? Transmission lines can be made in a number of physical configurations, one of the commonest being a central signal conductor, surrounded by a dielectric medium, surrounded by a signal return path in the form of a braided sheath. Any screening to the signal on the central conductor afforded by the braid must be considered as a bonus in the use of the cable. The braid is intended as the signal return path and the cable must be installed always with this as the prime consideration. If we want to protect a cable, we must add a screening braid; thus we arrive at a double braided cable with an insulating intersheath.

Having reasoned that a double braided cable with an insulating intersheath is the best form of flexible coaxial cable to use, we must now consider an earthing philosophy. Inside ships most of the interference power will be present at low frequencies from the mains supply of 50, 60 and 400 cycle per second and their harmonics. As we have seen a single point earth configuration gives us maximum attenuation to low frequencies, therefore our inner braid must have a single point earth. The outer braid is a screening braid and we must now compromise between low frequency attenuation for single point earthing, a cancelling effect to be gained by double point earth or a multiple point earth. This cancelling effect is due to the following; if the transmission line formed by the outer braid to earth plane is the same as that formed by the inner to outer braids, then the susceptibility curve for the one will be the inverse of the other and nodal frequencies for one will correspond to antinodal frequencies for the other, thus for the cable as a whole the susceptibility curve will be the vector sum of the two and will smooth out the excursions. For a multiple earth point system the effective cable lengths will be short and the loop areas formed between braid and earth plane small, hence induced interference powers will be smaller, also since the cable lengths are small the interfering frequencies will be higher to have any effect. On the basis of this reasoning we would therefore recommend, that for simple cables over short lengths, say from one compartment to another and less than 100 ft. a double point earth system should be used, for longer lengths or over more complicated routes multiple point earth configurations should be used. This applies only to the outer or screening braid, for the inner or signal return braid a single point earth with correct input balance arrangements. It is not right to leave the inner braid unterminated or unconnected; if this is done the signal return path is through the earth plane configuration and the interference must be increased.

Finally about earthing, it is worth mentioning that the length of earth straps from equipments to the ground plane are subject to the same considerations and a single point earth system should be used, bearing always in mind that at frequencies where the earth strap length is equivalent to a quarter wavelength the earth strap is effectively open circuit and the equipment is ungrounded.

Conclusion

In this paper I have only covered a few aspects of the interference problem as it affects the ships and men of the Royal Navy. I have highlighted only one or two specific areas which I believe are fundamental to any solution or alleviation of interference. As a result of this emphasis I have omitted mention of many other areas such as filters, equipment and system design. The terms of reference of the Radio Interference Section of A.S.W.E. are very wide and an attempt is made to cover the whole ground, as a result the limited effort available is spread rather thinly in many areas of study and we are bound to accept without verification the results of many other workers in the field.

To sum up then, there is an interference problem in the Royal Navy which has a latent potential to nullify all our complex and expensive electronic detection, communication and weapons systems. What price a cost effective solution which ignores such a danger that can render the solution unobtainable in practice ?

We are aware of the problem and by lectures to equipment contractors and to Naval Staff, by offering an advisory and consultative service to project and system engineers and by internally publishing interference suppression information and techniques as we become aware of them, we are widening the knowledge throughout the Navy.

At ship level where anti-interference work takes place at the coal face so to speak and where interference invariably gets worse, periodically carried out mutual interference trials and inspections offer a ready barometer to ships' staffs on how their equipments and systems are behaving. Interference

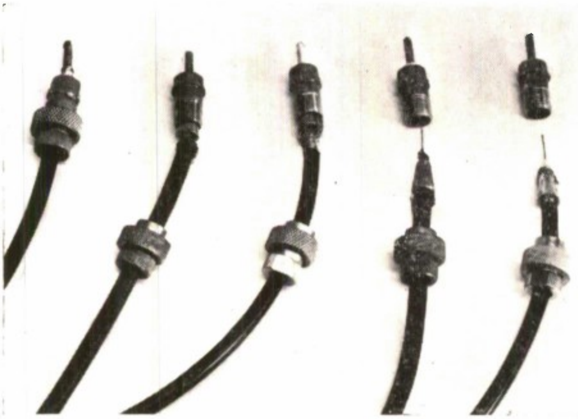


FIG. 19.

FIG. 20

techniques lectures aimed at equipment maintenance staff are regularly given at H.M.S. *Collingwood* and are going a long way to avoiding the bad maintenance which frequently contributes to a worsening interference situation at sea. Such simple things as badly made up plugs and sockets where the braids are frayed or broken (Figs. 19 and 20), ignorance of earthing requirements (Fig. 21), screening covers left off equipments because of the number of screws or bolts required to be replaced. The destruction of the screening effectiveness of radio offices due to ship staff jury rigged systems. The troubles caused by this sort of bad practice is becoming known throughout the fleet, resulting in a slight but definite overall improvement.

I said at the beginning I did not intend to mention specific problems but I am aware that my treatment of the subject has been biased towards radio and radar and omitted anything specific about electrical machinery and generating plant. I hope by this omission I have not given the impression that no problems exist in these areas. A ship must be an integrated system in which each section must work compatibly with the others and in taking an overall view we take into account all frequencies from D.C. to kilomegacycles generated at all powers by any means necessary.

FIG. 21.

I finish with a plea to all of you who have anything to do with electrics or electronics, the one frequency spectrum that nature allows has to be used by everyone, and all too much of it is over-filled. The plea I make is that you should be aware of the interference potential of equipment that you design, install, maintain or operate and that you should be aware of as far as possible its effect on other users of the frequency spectrum. Interference is not confined to the Royal Navy, it is a national and international problem. The M.O.D.(N) has thriving collaboration projects with France and the Netherlands with a mutually profitable exchange of information, expertise and experience. The subject has long passed the stage where it was considered that, here we have electrics and electronics and there with black magic we have radio interference. "Call in the expert" often confused with warlock and expecting a cure by incantation. We must all be experts, at least in the simple causes which contribute to a bad interference situation and the simple cures which at initial design and installation are all too easy to accommodate but which rapidly becomes prohibitively expensive as curative rather than preventive solutions.

Acknowledgement

The information and sources on which this paper has been based are so varied and many that a complete bibliography is impossible. I have therefore only given a list of some relevant reports and publications produced in A.S.W.E. in the last few years which are aimed at M.O.D.(N) personnel associated with electrics and electronics.

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[2] Surface Transfer Impedance of Solid Coaxial Cables. H. Salt. A.S.W.E. Laboratory Note Q-65-3.
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CANADIAN DEFENCE ESTABLISHMENTS—TITLE CHANGES

From 6th July 1967 the following Defence Research Board Establishments have been renamed.

From:—	*To:—*
Pacific Naval Laboratory—P.N.L.—Esquimalt, B.C.	Defence Research Establishment Pacific—D.R.E.P.
Defence Chemical, Biological and Radiation Laboratories—D.C.B.R.L.—Ottawa, Ontario.	Defence Chemical, Biological and Radiation Establishment—D.C.B.R.E.
Operational Research Establishment—O.R.E.—Ottawa, Ontario.	Defence Operational Research Establishment—D.O.R.E.
Suffield Experimental Station—S.E.S.—Ralston, Alberta.	Defence Research Establishment Suffield—D.R.E.S.
Defence Research Medical Laboratories — D.R.M.L. — Toronto, Ontario.	Defence Research Establishment Toronto—D.R.E.T.

Two establishments, the Canadian Armament Research and Development Establishment — C.A.R.D.E. — Valcartier, Quebec; and the Defence Research Telecommunications Establishment — D.R.T.E. — Ottawa, Ontario, remain unchanged.

Factors Contributing to *THE IMPINGEMENT CORROSION OF COPPER-NICKEL-IRON SEA WATER SYSTEMS*

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SUMMARY

Investigations into the causes of impingement corrosion in H.M.A. ships led to a series of laboratory trials in which 95/5 and 90/10 copper-nickel-iron and 70/30 cupro-nickel piping was tested in a once-through sea water rig under controlled conditions in respect to water velocity, water rotation and flanged joint geometry.

These trials showed that an empirical relationship exists between water speed, joint error due to misalignment or jointing protrusion and depth of attack due to impingement corrosion, in which the depth of attack for a given water speed is proportional to the square of the joint error. This emphasises the importance of good workmanship in fabrication and fitting of pipework to ensure minimum misalignment and eccentricity at flanged joints.

In general, the ship and laboratory investigations have highlighted the importance of care in design, workmanship and operation in controlling impingement corrosion in ships' sea water systems.

Introduction

This report covers an investigation into the factors contributing to impingement corrosion in copper-nickel-iron sea water piping systems in H.M.A. ships. The investigation was prompted by the high rate of failure of 95/5 copper-nickel-iron sea water piping by impingement corrosion on the down-stream side of flanged joints in Daring Class destroyers and Type 12 Frigates.

Examination of ships' sea water systems and actual water speed measurements confirmed that relatively high water speeds were common in many parts of the firemains and that speeds above the range of the flow measuring equipment (15 ft/sec) existed in small branch lines.

A contributing cause of this high water speed was the deliberate overboard discharge of water to reduce firemain pressures and the use of firemains for auxiliary cooling due to lack of confidence, which was often well founded, in auxiliary pumping equipment.

Many small lines to auxiliaries permanently supplied from the firemains lacked proper flow control or had pressure reducing valves fitted which served no useful purpose.

However, impingement corrosion had also been encountered where water speeds were below the maximum speed of 10 ft/sec recommended for 95/5, especially where joints were badly aligned or had protruding jointing to act as turbulence raisers.

Laboratory Investigations

The literature on the subject of impingement corrosion in copper-nickel-iron indicates that, with material of the optimum composition, this form of attack is primarily a function of water speed and turbulence, and this has led to the general acceptance of 10ft/sec as the upper safe limit for sea water in 95/5 copper-nickel-iron. In the Royal Navy failures of 95/5 copper-nickel-iron have been common as indicated by Kenworthy[(1)] who drew attention to various practical aspects of the problem, including the necessity for controlling water speeds and ensuring good workmanship at flanged joints.

Additional factors which could affect the rate of impingement attack are, rotation of the water, degree of aeration and heat treatment (metallurgical condition of the copper-nickel-iron).

In view of the magnitude of the problem of repeated failures of copper-nickel-iron sea water systems in H.M.A. ships, an investigation was commenced to determine the relative importance of the principal factors, namely, water speed and flanged joint condition, in causing corrosion impingement failures in 95/5, 90/10 and 70/30 copper-nickel-iron, by a series of trials in a once through sea water testing rig. As an adjunct to the pipe tests, a series of impingement tests was undertaken to determine the effects of heat treatments, cold working and bi-metallic contacts on copper-nickel-iron.

Impingement Tests

For the impingement tests a modified Brownsden and Bannister apparatus was used in which 12 No. specimens, including a control, were tested simultaneously.

Work by Bailey[2] indicated that heat treatment would affect the impingement resistance of 95/5 copper-nickel-iron, but subsequent Admiralty experience showed no significant change in impingement resistance when 95/5 copper-nickel-iron was subjected to heat treatments likely to occur during brazing operations[1]. In the present investigations, sections of 95/5 and 90/10 piping were analysed to ensure that they conformed with specification requirements, namely 5-6% nickel, 1-1·4% iron, 0·5 - 0·8% manganese, remainder copper and 10 - 11% nickel, 1·4 - 1·7% iron, 0·5 - 1·0% manganese, remainder copper respectively, and samples cut from these pipes were given various treatments and tested for impingement resistance for 1,000 hours as shown in Table 1.

The impingement tests showed that the heat treatments and cold working had no significant effect on impingement resistance.

TABLE 1. Results of Impingement Tests.

Test No.	*Specimen and Condition*	*Depth of Attack ins.*	*Remarks*
1	*Copper—as received*	0·012	Approximately twice the depth of attack in C.N.I.
2	95/5 Copper-Nickel-Iron		
(a)	As received		
(b)*	Heat treated for ½ hour as follows: (i) 600°C (ii) 650°C (iii) 700°C (iv) 800°C (v) 900°C	All tests 0·006 to 0·008	No significant difference in depth of attack for specimens 2(a) to 2(e).
(c)	Samples from pipes which had failed.		
(d)	Work hardened by hammering.		
(e)	Coupled to the following copper alloys. (i) Brazing metal. (ii) Gunmetal—88/10/2.		
3	90/10 Copper-Nickel-Iron	0·0035	Material "as received."

* Note.—The heat treatments were restricted to ½ hour as it was considered unlikely that pipes would be heated for longer periods during fabrication.

Pipe Test No. 1

A series of tests was undertaken on copper-nickel-iron pipe-work on the once through pipe testing rig in which conditions of flow and turbulence were carefully controlled.

Straightening vanes were used ahead of some pipes to ensure that water entering did not rotate, while in others, a device was used to cause a rotation of approximately 1,060 rev/min. In this way the motion of the water in each section was known.

Particular care was taken to ensure that pipes were accurately made and correctly aligned with well cut jointing.

Approximately 85% of the flanged pipes initially supplied for the test were rejected after a dimensional check of the bore and had to be re-made. Although the pipes appeared satisfactory to a casual inspection, it was found that the bore size at the flange varied considerably from pipe to pipe. Some were over- or under-size, while others were bell-mouthed or oval. Pipe tolerances accounted for some differences, but most were due to fabrication techniques which involved expanding or swaging in the pipe to suit the flanges supplied.

The test rig consisted of two sections in series, each containing 95/5, 90/10 and 70/30 pipes. One section comprised 1¼ in. diameter pipes and the other 1½ in. diameter pipes and flow was adjusted so that a water speed of 10 ft/sec was obtained in the small diameter pipes and 7 ft/sec in the larger.

In assembling the pipes, adjacent bores were matched to within 0·005 in. and no champher or radius was permitted in the bore. In each section

TABLE 2. Results of 1st Pipe Test (7 and 10 ft/sec)

Flow Conditions	*Pipe Shape*	*Pipe Material C.N.I.*	*Condition of Jointing*	*Remarks*
7 ft/sec with straightening vanes ahead of each pipe	Straights and "U" bends	95/5 90/10 70/30	Correctly cut	No attack
		95/5	1/16 in. protrusion one side only	Pitting attack adjacent to protrusion of jointing up to 1 in. from flange face
		90/10 70/30	,, ,,	Slight surface roughening up to $\frac{1}{8}$ in. from flange face on some pipes only
10 ft/sec with straightening vanes ahead of each pipe	Straights and "U" bends	95/5 90/10 70/30	Correctly Cut	No attack
		95/5	1/16 in. protrusion one side only	Pitting attack adjacent to protrusion of jointing up to 1 in. from flange face. No attack in the bends
		90/10 70/30	,,	Slight pitting close to flange. No attack in bends
10 ft/sec with screw down valve ahead of pipe	Straight	90/10	Correctly cut	No attack (1-No. pipe only tested after a valve)
10 ft/sec with vanes to cause rotational motion *i.e.* 1060 rev/min approx.	Straights	90/10	Correctly cut	Light erosion over entire inner surface.
		70/30		No attack
	"U" bends	90/10	Correctly cut	Pitting attack throughout entire bend in a spiral pattern (Fig. 1)
		70/30	,,	Pitting attack throughout entire bend—random pattern

a number of joints were made with jointing protruding eccentrically into the bore.

The test was continued for a period of five months without interruption. The pipes were then disassembled, cleaned and inspected. The results are shown in Table 2 and demonstrate the fact that impingement attack does not occur with well made joints, *i.e.* adjacent bores matched to within 0·005 in. and with water speeds of up to 10 ft/sec and also suggest that a relationship might be established between water speeds, joint error due to misalignment or jointing protrusion and depth of attack.

The corrosion effects of rotational motion were also demonstrated.

Pipe Test No. 2

A second series of pipe tests was undertaken to determine the type and extent of attack likely to result from a range of joint conditions. For these tests 90/10 only was used as this alloy had been adopted for general use in H.M.A. ships.

The test period was three months' continuous running at 17·5 ft/sec for each series and the joint conditions tested and the results obtained are shown in Table 3.

TABLE 3. Results of 2nd Pipe Test Series

Joint Condition	*Result of Test—90/10 C.N.I. Water Speed 17·5 ft/sec*
1. Well made — errors less than 0·01 in.	No attack
2. Adjacent bores misaligned: (a) Jointing aligned with upstream flange.	Erosion commenced around edge of pipe when the offset exceeded 0·015 in. approx. and gradually extended up bore (Fig. 2) Above 0·02 in. offset, grooving occurred at edges of overlap. Over 0·05 in., attack commenced up to 3 in. from flange face.
(b) Jointing aligned with downstream flange.	Erosion commenced near flange face when the offset exceeded 0·015 in. approx. Above 0·02 in. offset, erosion extended up pipe and grooving commenced at edges of overlap. Over 0·05 in. swept attack commenced 2 in. to 3 in. up pipe (Fig. 3)
3. Jointing only offset pipe bores matched within 0·005 in. and correctly aligned.	Erosion commenced when protrusion into bore exceeded 0·015 in. approximately. Attack similar to 2 (b)
4. Jointing badly cut with irregular protrusions into bore. Bores matched within 0·005 in.	Erosion occurred near flange face and varied with the size of the protrusion. Some pitting 2 in. from flange face.
5. Jointing protruding into bore evenly all round. (a) 0·03 in. protrusion all round.	Some pitting near flange with light swept attack up to 2 in. from joint face.
(b) 0·125 in. protrusion all round.	Light swept attack approx. 3 in. up pipe with some pitting. No attack adjacent to flange face.
6. Adjacent bores of different diameter or bell-mouthed.	Erosion commenced at the joint and extended up pipe. Extent of attack was proportional to the maximum error.
7. Pipe not flush with joint face.	Erosion commenced at pipe edge and extended up bore.
8. Rubber jointing used in lieu of C.A.F. Bore cut 1/32 in. oversize.	Erosion close to joint face. Water marks confirmed that jointing had squeezed into bore.

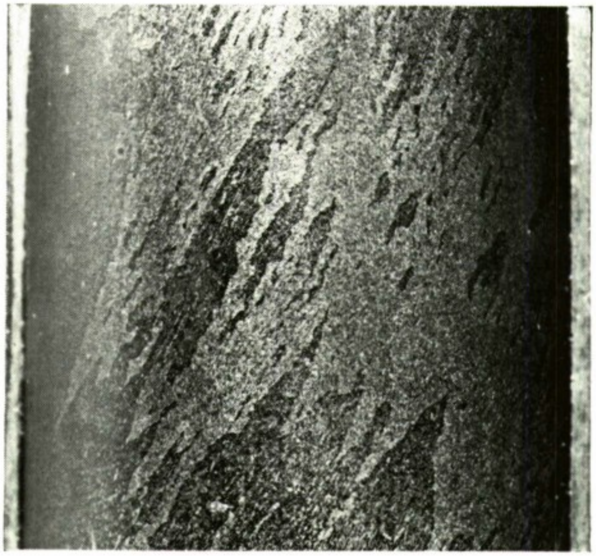

FIG. 1. Spiral corrosion pattern in a bend due to rotational motion of water.

Discussion of Results

The tests indicate that eccentricity of mating flanges or protrusion of jointing material into the bore is of extreme importance in the development of impingement attack and demonstrates the necessity of carefully defining what is required in the way of workmanship in fabrication and fitting of copper-nickel-iron sea water piping. If this is not done, the maximum water speeds for particular materials which are frequently quoted, have no real significance.

The desirability of defining, in dimensional terms, the quality of workmanship required in pipemaking has underlined the necessity for a technical

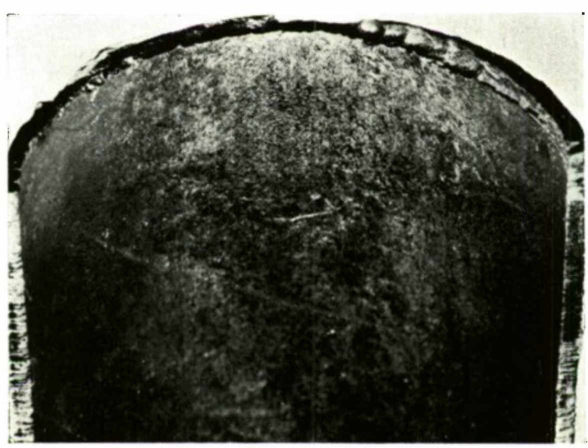

FIG. 2. Erosion around end of pipe due to offset pipe bores.

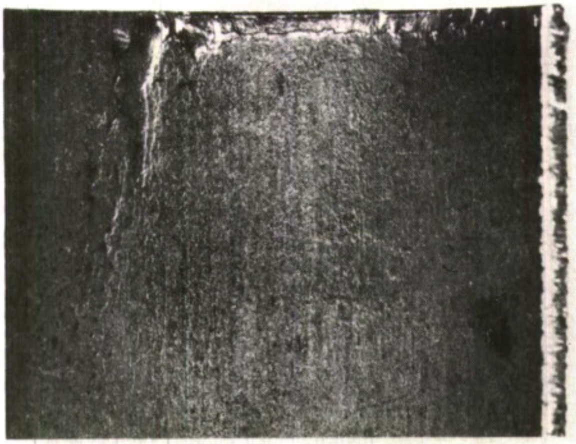

FIG. 3. Attack on pipe edge due to misalignment. Grooving has commenced at point of overlap.

instruction and drawings laying down specific tolerances for fabrication and fitting of pipework. Such instructions have recently been prepared.

A detailed study of results of the pipe tests indicated that the depth of attack was proportional to joint condition, *i.e.* maximum error resulting from misalignment or joint protrusion, average water speed and time of operation, *viz.*,

Depth of attack $\propto$ Time $\times$ Velociy $\times$ Error at Joint or $d \propto T^a \times v^b \times e^c$

By varying each parameter in turn, a series of tests showed that

$d \propto Tve^2$ ($a=1$, $b=1$, $c=2$)

where d=depth of attack in inches
T=time in years
v=velocity in ft/sec
e=maximum error at joint in inches

FIG. 4. Attack due to protusion of irregularly cut jointing.

The approximate time for complete penetration of a particular pipe can be obtained by substituting "t" (pipe thickness in inches) for "d" and transposing, *i.e.*,

$$\text{Time} = T = \frac{K.t}{ve^2} \text{ years}$$

where K=proportionality constant for materials used.

Values of K determined from tests are as follow=

95/5 C.N.I.	K=0·35
90/10 C.N.I.	K=0·5
70/30 C.N.I.	K=0·6

The values for 95/5 and 70/30 are less accurate than those for 90/10 due to the limited testing of these alloys. However, the tests confirmed the slight superiority of 70/30 over 90/10. In practice, for use in ships' sea water systems, this advantage in resistance to impingement of 70/30 is offset by higher cost, greater fabrication difficulties, particularly in respect to heating and a lower resistance to marine fouling attachment.

It can be seen that an increase in the joint error "e" which is squared in the above formula, has a greater influence on the life of piping than an increase in water velocity.

In the case of 90/10 piping with a maximum water speed of 10ft/sec no significant attack should occur if the joint error is less than 0·015 in. A life in excess of twelve years is indicated by the formula for this error, but any increase in this value could cause a drastic reduction in pipe life. The importance of the maximum joint error on impingement indicates that this form of attack is a "local" phenomenon and should not be significantly influenced by variation in pipe diameter within reasonable limits, say 1 in. to 5 in. However, this aspect could not be investigated in practice due to the limited capacity of the testing rig.

The formula does not take into account factors such as temperature or degree of aeration, which are likely to be variable in service, but it is assumed that their effects are small compared with the likely accuracy of the calculations based on the use of the formula. Further, perforation of particular pipes may occur inside the flange and the time taken for actual leakage will therefore be considerably longer than calculated.

The results of the second test, in particular, indicate that joint errors of different types, *i.e.* misalignment or protruding gaskets produce similar intensity of attack, which depends on the magnitude rather than the type of error. However, when jointing protrudes evenly into the bore all round by an amount approximately equal to the pipe thickness or greater, jetting up the bore occurs

and the attack is spread over a larger area and is generaly less severe, so that the formula does not apply.

In the first test where a substantial rotational motion (1060 rev/min) was imparted to the water stream in one section, results indicated that it had only a marginal effect on impingement attack at joints, which is largely controlled by local joint conditions. However, as indicated in Table 2, rotation of the stream caused a general pattern of attack, particularly in bends. In respect to rotational motion, it should be emphasised that severe rotation to the extent of vortexing can be produced by abrupt changes in cross sectional geometry. This has been found to occur with certain types of so-called "straight through" diaphragm valves[3]

In view of the importance of joint conditions as a cause of impingement attack, it is probable that rough cast valve bores, which are also sometimes eccentric, are responsible for failures previously associated with turbulence due to particular valve designs. This also applies to fittings such as tees, elbows and even the outlets from heat exchanger water boxes.

Conclusion

The series of tests on 95/5, 90/10 and 70/30 copper-nickel-iron pipes, together with investigations of failures in ships' sea water systems, has demonstrated the importance of design, workmanship and operation of these systems in controlling impingement corrosion. The following particular aspects require special attention.

Design

The design of each system should ensure that water speeds are adequately controlled and are not excessive for the materials used and the standard of workmanship. Fittings likely to cause rotational motion of the water stream should not be used. The use of flow controllers in firemain branch lines is of particular importance and the actual measurement of flow rates in new installations is strongly recommended.

Workmanship

The standard of workmanship in pipe fabrication and fitting should be of a high order and should be closely specified in standards and codes of practice, the most important requirements being—

(a) Jig drilled and accurately machined flanges which assure correct brazing clearances without the necessity of operations such as expanding or swaging the end of the pipes.

(b) Die cut jointing.

(c) Correct assembly techniques to eliminate misalignment of joints.

(d) Fittings, particularly valves and tee pieces to have machined bores to match pipe diameters.

Operation

Sea water pumps in ships should be operated with the correct discharge pressure and overboard discharge of water must be restricted to the minimum for adequate cooling. The supply of cooling water for auxiliaries from the firemain should be kept for emergency use only.

In general, while the use of 90/10 copper-nickel-iron should reduce the incidence of service failures in sea water systems, it must be emphasised that this higher duty material alone will not cure piping troubles without proper attention to design, workmanship and operation.

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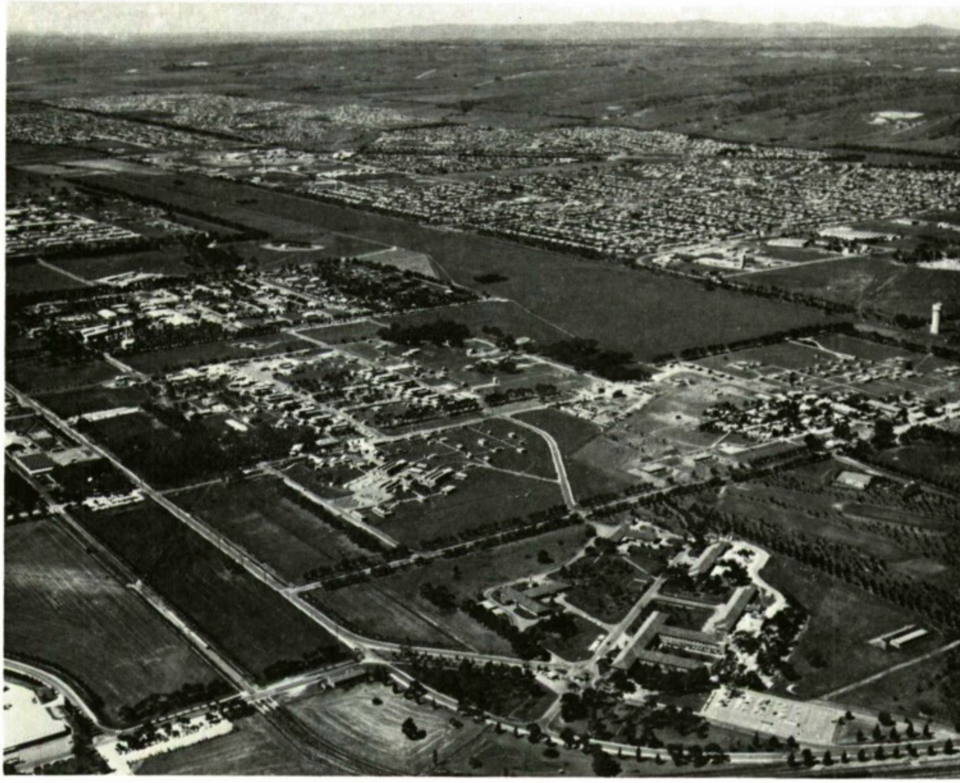
Skylark Launch

THE WEAPONS RESEARCH ESTABLISHMENT

J. M. Maddern
W.R.E. Salisbury, Australia

Early History

Following discussions between the Governments of Great Britain and Australia, the present Weapons Research Establishment which includes Woomera was set up in 1947 in the State of South Australia. The purpose of the discussions was to see if suitable facilities could be provided in Australia for the long-range testing of guided weapons, and research using rocket test vehicles, in support of a long term development programme on which the British Government had embarked. It was found that space could be provided in Australia for such ranges extending for up to 1,200 miles over practically uninhabited country. It was also found that at Salisbury, near Adelaide, there existed a war-time munitions plant no longer required for its original purpose, which could provide 2½ million square feet of accommodation suitable for conversion to laboratories, workshops and other facilities, on a scale which would enable adequate scientific and engineering support to be given to the project. The two Governments thereupon entered into a joint agreement to exploit these facilities, an activity sustained until today and commonly referred to as the Joint Project. The Establishment was created within the Research and Development Branch of the Australian Department of Supply.



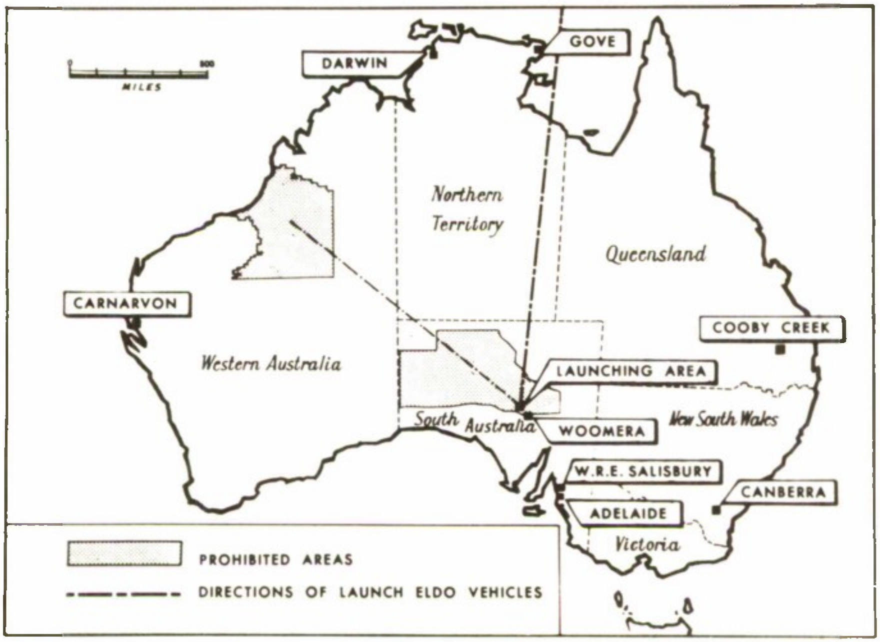
Aerial View of Salisbury, showing part of the $6\frac{1}{2}$ square miles of W.R.E. The new satellite town of Elizabeth is in the background.

Naval Captain as Superintendent, Woomera

The Weapons Research Establishment today employs over 4,000 people at the Establishment at Salisbury and over 1,000 at the Woomera Range some 320 miles to the north. Employees' families and logistic support raises Woomera's population to the region of 5,000. The post of Superintendent at Woomera is filled in turn by officers of the three Services and Captain J. B. Newman, R.A.N. (retired) was in office as Superintendent for the two terms from 1954. The current Superintendent at Woomera is also a Naval Captain, Captain F. E. Irvine, R.A.N. who commands a mixed Service (but no Navy) and civilian population in a semi-desert area, far from the sea. The two parts of the Establishment are connected by rail and road, and in addition Service and chartered aircraft are used to provide both air support for trials and transport for passengers and freight. A Royal Australian Air Force Establishment which provides all experimental and flying requirements for W.R.E. is an integral part of the Establishment and is based on Edinburgh Airfield adjacent to the Salisbury H.Q.

Joint U.K.-Australian Projects

The organization at Salisbury has been divided into five Wings according to function. The principal Range operations are conducted within the Trials Wing which is responsible for the provision of the instrumentation systems at the Range and for the planning and conduct of the trials. The trials programme under the Joint Project is considered by a Joint Committee (Joint Project Policy Advisory Committee) on which both the Australian and U.K. Governments are represented. Both countries, can, and indeed do, submit proposals to JPPAC. The planning of the trials is worked out in close collaboration with the contracting firms, and leads to the preparation of Trials Specifications which lay down the procedures to be followed in all necessary detail. The individual trials are conducted jointly by the resident Range staff and contractors' personnel and result in large quantities of tape, film and other recorded material which is the output of the various instrumentation systems used. The reduction of these data to manageable forms within the time provided is a major function undertaken at Salisbury by the Trials Wing in a data processing system which includes an *IBM* 7090 digital computer.



Distribution of Space Activities of W.R.E.

Optical and Electronic Instrumentation Systems

The instrumentation systems in use fall broadly into optical and electronic categories. Optical systems have a particular advantage at Woomera since the climate is typified by comparatively long periods of fine weather with good visibility and freedom from cloud. Optical systems include high-speed cameras to record the behaviour of rounds in flight and tracking systems using networks of kinetheodolites and ballistic cameras. However, it is found that the extraction of visual tracking data from film in forms suitable for subsequent machine processing is laborious and slow, even with the aid of semi-automatic film-recorders. Therefore, for some purposes, methods which permit magnetic recording of data are preferred.

Electronic instrumentation systems include multi-channel telemetry systems to record the internal behaviour of rounds in flight, and tracking systems using pulse and doppler radar techniques, and a Missile Tracking System in which an air-borne beacon is tracked by a ground network of auto-follow receivers. By digitizing data from the tracking system information can be transmitted continuously over lines to a plotting and recording Tracking Data Centre located in the main Instrumentation Building. The recordings on magnetic tape are in a form suitable for direct processing in the data reduction system at Salisbury.

These instrumentation systems require continual upgrading and are themselves subject to continuous research and development by W.R.E. This need has been continuous throughout the earlier research and development trials of *Fireflash, Firestreak, Red Top* (air-to-air), *Bloodhound, Thunderbird* (ground-to-air), *Seaslug* (surface-to-air), *Malkara* (anti-tank) and *Ikara* (anti-submarine) all of which were tested at Woomera. Bracketed with the military programme, which currently includes *inter alia* the Royal Naval version of the Australian *Ikara* anti-submarine weapon, *Rapier* (a lightweight anti-aircraft weapon) and *Sea Dart* (naval surface-to-air weapon), is the further development of the *Jindivik* target aircraft to reproduce more closely the expected performance of typical enemy aircraft.

Upper Atmosphere Research

Apart from its military programme, the Establishment has a long and continuous interest in upper-atmosphere and near space research work, resulting from the availability of Woomera for the firing of sounding rockets. A certain amount of such work has been done by rockets of local design and construction, such as *Long Tom, HAD, HAT, Aero High,* but a very much larger and more ambitious programme has been based on the rocket *Skylark*. This rocket was designed in Great Britain and the experimental programme is controlled

The 85 ft. parabolic antenna at the Deep Space Instrumentation Facility No. 41.

through the Space Research Management Unit of the U.K. Science Research Council which co-ordinates experimental programmes devised by a number of British universities. *Skylark* is able to take sizeable instrumentation loads to heights up to 150 miles. More than 150 firings have been made, as a result of which a great deal of new data have been obtained about the Earth's environment.

Launchers—Major Engineering Tasks

A number of firing pads have been installed at the Woomera Rangehead. These have been designed by the Engineering Wing to be largely independent of each other and are complete with individual Test Posts and Equipment Centres so that work can proceed in parallel on a number of projects. Two specialist firing areas have also been constructed, one for *Black Knight* and the other for the ELDO sponsored trials. The *Black Knight* programme which ran for a number of years was completed in late 1965 with a record 22 successful firings out of 22 launches. *Black Knight* was used to investigate re-entry problems from heights exceeding 500 miles. The *Black Knight* firings conducted under the *Dazzle* programme have now been followed by the *Sparta* programme which has similar aims as the *Dazzle* programme but using the much larger American *Redstone* rocket under the same tripartite (Great Britain, Australia, U.S.A.) agreement. The first *Sparta* firing took place on 28th November, 1966.

European Launcher Development Organisation (ELDO)

The ELDO Satellite Launcher Vehicle consists of the British *Blue Streak* first stage, the French *Coralie* second stage, a German third stage, an Italian satellite with Belgium and the Netherlands responsible for associated electronic and tracking systems. The first firing of the multi-stage, multi-national *Europa 1* was conducted successfully at Woomera on 24th May, 1966; and the second on 15th November, 1966; these were the largest rockets ever to be fired from Woomera, and indeed anywhere outside the U.S.A. or U.S.S.R.

The ELDO launcher, referred to locally as Launcher 6, is located five miles from the Rangehead. It is a massive concrete structure jutting out over an escarpment 150 ft. above the surface of Lake Hart, a generally dry salt-encrusted lake. On top of this structure is a 130 ft. high Servicing Tower which encloses the rocket assembly during the preparation stages, and which is rolled back to the far end of the causeway during trials. Below the rocket emplacement is a dry duct, lined with heat-resistant tiles, to deflect the hot gases out over the Lake bed. Beneath the deck of the causeway a number of Test Posts are accommodated together with reticulation systems for kerosene, liquid oxygen, high-pressure nitrogen gas, water and a number of other missile and launcher services.

The provision of fuel and oxidants to the launcher site has been a considerable engineering undertaking. A plant capable of manufacturing 100 tons of liquid oxygen per week was constructed

Ikara the anti-submarine weapon developed by the Australian Department of Supply.

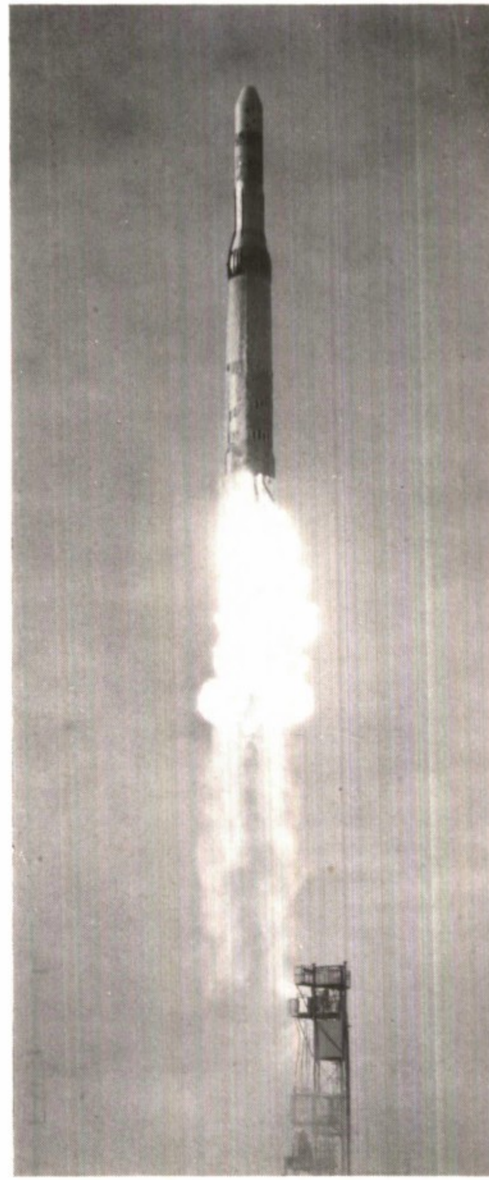
at Woomera. The process is one in which air is liquefied and separated into its liquid oxygen and liquid nitrogen components in a fractionating tower. The liquid components are separately stored in 16,000 gallon tanks built with inner and outer containers separated by a space which is perlite filled and evacuated. The inner shell is made of stainless steel and contains some 80 tons of liquid oxygen or 56 tons of liquid nitrogen. The liquids held at the plant in five such tanks are taken as required to the launcher site in road tankers of similar construction from which they are transferred to a site storage system of three tanks.

In all trials at Woomera great care is taken to see that rocket debris does not fall outside prescribed boundaries; these precautions have become more important as rockets grow in size and range. For the ELDO rocket, from the earliest stages of lift-off, the course of the missile is followed continuously by a system of sky-screens, optical instrumentation and radar, and the data obtained fed into a large Digital Impact Predictor specially designed and built for the purpose by W.R.E. By this means a continuous plot is traced throughout the trial of all possible impact points and the main propulsion motors are cut off if any of these points should cross a boundary.

U.S.A.-Australian Projects

In addition to these programmes, undertaken jointly with the U.K., U.S.A. and ELDO, a sizeable effort in the Space Physics Wing is concerned with various American projects undertaken by agreement between the Australian and U.S. Governments. These projects are all concerned with aspects of satellite tracking and space research sponsored by the U.S. National Aeronautics and Space Administration.

The 3-stage Europa One undergoing pre-flight tests. The servicing tower is in the withdrawn position.



Europa One F4 launch

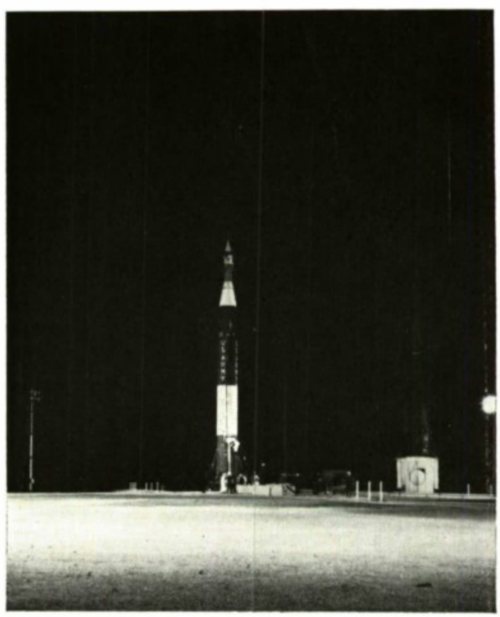
It began with a Minitrack station at Woomera, as part of a world-wide network of radio interferometers used for measuring orbital data of American satellites and for recording data transmitted by them. This was followed by the installation of a Baker-Nunn tracking camera. With this instrument, the clear atmosphere at Woomera enabled some outstanding records to be taken of small satellites at great distances.

Europa One F5 launch
15 November 1966

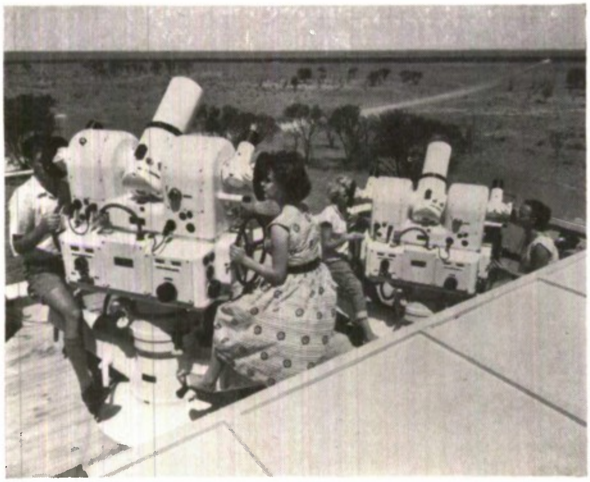
These instruments, which were concerned with earth satellites, were shortly supplemented by others to be used for the exploration of inter-planetry space. For this purpose another world-wide network of stations, the Deep Space Instrumentation Facility, was set up. Each station was equipped with an 85 ft. parabolic aerial which would automatically track radio transmission from space craft. As early as February 1961, the first of these installations (at Woomera) participated in a moon-bounce experiment with the parent station at Goldstone in California. Over a period of some hours, mutual visibility of the moon at these two stations enabled verbal messages to be sent, and greetings were exchanged by this unique means between the Australian Minister for Supply and the Deputy Administrator of NASA. A second Deep Space Instrumentation Facility has since been established at Tidbinbilla near Canberra, and came into operation in time to participate in the *Mariner* "flyby" of planet Mars in July 1965.

The Canberra area is also the location of two other tracking centres. One of these is the STADAN Space Tracking and Data Acquisition Network station at Orroral whose purpose is connected with near-earth scientific investigations. This station also is equipped with a steerable 85 ft. diameter parabolic aerial, and in addition the Minitrack system, originally installed at Woomera, has been transferred to this site. Initially the station is participating in a programme of orbiting observatories comprising the Eccentric Geophysical Observatory (EGO), Orbiting Astronomical Observatory (OAO), and Polar Orbiting Geophysical Observatory (POGO) satellites, but it also tracks and records data from a number of others.

Another tracking station has recently been opened at Cooby Creek, near Toowoomba in Queensland. Here a 40 ft. diameter tracking aerial, and associated vans of equipment, are used to support the Applications Technology Satellite programme whose main objectives are to conduct experiments on spacecraft control, communications and meteorology.



The American Redstone first stage boost of the 3-stage rocket used in the Sparta programme undergoing pre-flight checks.



Theodolites at Woomera.

A ballistic camera site.

The IBM 7090 Computer.

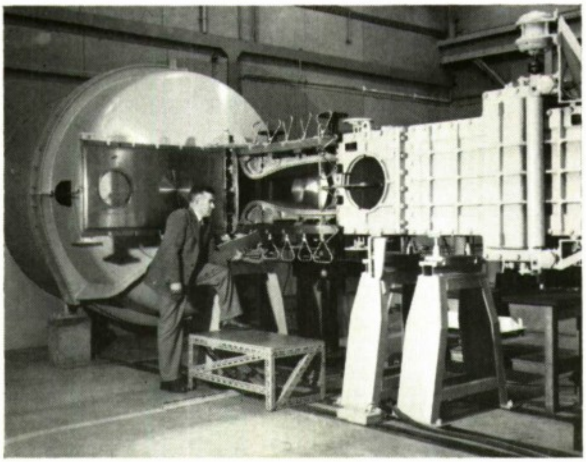
Australia has participated in the manned space-projects of the U.S. since their beginning. Initially the Mercury programme required the setting up of a tracking and communication centre near Perth in Western Australia and this station performed an important function in the first U.S. manned flight when Commander John Glenn orbited the earth. However with the advent of *Gemini*, improved facilities were installed at the preferred site at Carnarvon 600 miles further north. The Carnarvon station has played an important rôle in subsequent *Gemini* flights.

A third station in the Canberra area is at Honeysuckle Creek where preparations are being made for project *Apollo* which is the third phase of the NASA manned spaceflight project during which it is planned to make actual moon landings. This station also will be equipped with an 85 ft. diameter steerable aerial, and will share with stations in Spain and California, the task of communicating with the *Apollo* spacecraft during all phases of its mission.

Information from tracking and deep space stations is used in research programmes at Salisbury. Currently V.L.F. records and records of decameter emissions from Jupiter are being used. In addition, information from scientific satellites is supplied for a number of ionosphere studies which are being undertaken here and at several Universities. In the near future records of solar events will be used on studies of V.L.F. propagation and interplanetary plasma.

Basic and Applied Research

This same Wing—the Space Physics Wing—also engages in a variety of basic and applied research programmes such as the study of electro-magnetic phenomena associated with the hypersonic flight of bodies in the earth's atmosphere; the study of the propagation of coherent and incoherent light and infra-red radiation in the atmosphere; research and development into new techniques and devices of interest to W.R.E., particularly in the fields of lasers and microminiaturisation. It also provides electrical, electronic and photometric standardising and calibrating services and generates standard frequency and time signals. It provides expert services in the design of aerials and passive electromagnetic devices such as microwave components and filters, radar data and display systems, and analogue, digital and hybrid computing equipment. It uses computers for the analysis of guided weapon systems using the mathematical model technique, and for the mathematical study of offensive and defensive systems on behalf of the Armed Services.

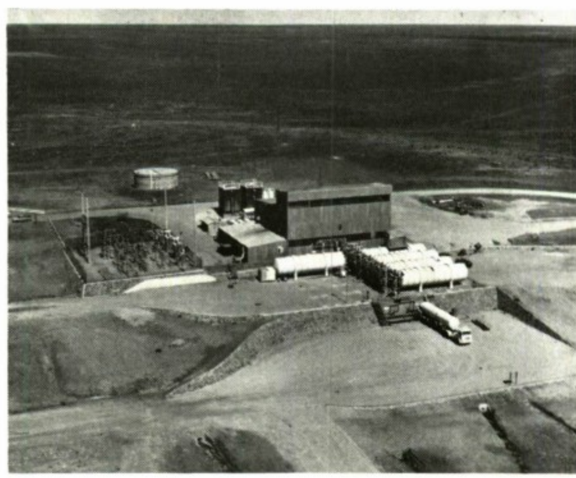


Wind Tunnel working section at W.R.E.

programme has been in operation for a number of years, and has led to a much better understanding of the behaviour of a bomb when released from an aircraft and in its subsequent flight through the atmosphere.

Effort is also being devoted to research on night vision aids using both infra-red techniques and image intensification; to the development of improved submarine detection systems, to work on solid propellants for rocket motors; and to many other tasks of defence significance.

These varied activities of the Weapons Research Establishment, developed originally around the Joint U.K.-Australia Project Agreement have, over a period of nineteen years expanded to embrace much wider and comprehensive fields than were probably ever envisaged in 1947. During its development and expansion, the scientists, engineers and technicians at W.R.E. have accumulated a vast amount of experience which enables Australia now and in the future to make a significant contribution to its own defence and that of its allies, to participate in international co-operative programmes for the exploitation of space for peaceful purposes, and in so doing to create and maintain in Australia a high level of competence in advanced technology.



The air separation plant capable of producing 100 tons of liquid oxygen per week.

Scientific Support for Australian Armed Services

Other work for the Armed Services is being carried out by the Weapons Research and Development Wing, a Wing, as its name suggests, originally formed as part of the scientific backing essential to the defence of Australia. A large amount of the effort in the Wing is concerned with *Ikara* which is being used by the R.A.N. as its main anti-submarine weapon. *Ikara* has been fitted to H.M.A.S. STUART and H.M.A.S. DERWENT, installation on H.M.A.S. PERTH and other ships is expected to be completed early 1967. The Wing covers responsibilities for the guidance system and for the rocket motor. The *Ikara* system is also being adopted by the R.N.

The Wing has a supersonic wind tunnel capable of reaching a Mach number of nearly three. The tunnel is being used mainly in support of dynamic stability studies. Data from models are fed into the Establishment's digital computer and the behaviour of the full scale aeroplane or missile predicted. Where possible, the predictions are checked by full scale tests, or by free flight model trials.

The performance of bombs using the above technique has been investigated in collaboration with America and the U.K. A co-operative research

TELEMETRY OF PISTON PARAMETERS AT ELEVATED TEMPERATURES

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SUMMARY

A system is described whereby piston information is continuously monitored using frequency modulation of carriers in the band 2 to 10 mc/s. The basic design of a miniaturised one channel transmitter for temperature measurement has been completed and practical details are given in the text. A thermistor was used as sensor. Trials with two operating channels have been carried out on a Lister engine over periods exceeding five hours without component replacement. The choice of high frequency band was influenced by the desire to avoid the use of an iron cored sensor when the measurement of displacement was to be considered.

Introduction

'Experience retention' is a term particularly applicable to designers of internal combustion engines for the simple reason that it is not known what really happens regarding relative movement between the piston rings, the piston and the cylinder walls of a working engine. Nor is it strictly known what is the state of the oil between these items. It is, however, known that wear and distortion of these parts do eventually occur, possible causes being continuous hammering due to mechanical movement, oil contamination by the products of combustion that pass the piston rings, and oil deterioration by momentary increases in temperature beyond vaporisation level. The lack of suitable instrumentation has hitherto hampered efforts to acquire this knowledge. If such instrumentation were available, it is confidently expected that it would enable one to establish quickly what performance uprating could be permitted and also what long term side effects might be encountered if an apparently worthwhile improvement were to be introduced without long term experience.

In the search for such improvements, information on piston temperature, for example, is currently obtained from small "fusible" plugs which are screwed into the piston at selected sensing points. These are examined after dismantling the engine and give an indication of the temperature reached at each of these points. A similar method, but using "hardness" plugs which are afterwards submitted to metallurgical examination, gives an indication of terminal temperatures reached over somewhat closer intervals than with fusible plugs. A third method involves sampling the parameter once per cycle of (a) contacts fitted to the piston underskirt which make with corresponding contacts on the cylinder at bottom dead centre thus connecting (say) thermocouples in the piston with external recording instrumentation [1, 2] or (b) coupling coils which replace the contacts [7].

None of the above three basic methods are, however, capable of providing continuous information so that interstroke variations of temperature, dynamic strain, or piston or ring movement with reference to the cylinder, can be determined. Some success in this direction with reasonably reliable and interpretable results has been achieved by the use of flying or highly flexible leads or by the use of mechanical linkage systems, but always at the expense of modifications to the crank case [3, 4, 5]. This, however, is not an invariably acceptable feature for this kind of investigation, nor is it lacking in tediousness in its application.

Non-contact telemetering systems to give continuous information have also been publicised [6] but, as far as the author is aware, the results have not been altogether successful. The telemetering arrangement described here has been tried initially for temperature measurement on two channels with satisfactory results, and is now being progressed for the measurement of other parameters.

Present System

The basic arrangement consists of a temperature measuring sensor S (Fig. 1) in the form of a thermistor connected to its own miniaturised transmitter, the latter being mounted on the skirt of the piston where the temperature does not exceed 100°C. The transmitter is frequency/temperature stable in its own right, within practicable limits, from ambient up to 100°C, at a frequency that is controlled only by the sensor's resistance or equivalent temperature. The controlled frequency change is limited to a rise of approximately 1 mc/s by a temperature rise in the sensor environment up to 300°C.

The transmitter signal is capacity (C_{01}) coupled to an electric line on the con-rod, whence the output is again capacity (C_{02}) coupled to a fixed external receiver. These capacitances are designed to remain fairly constant throughout each cycle of movement so that undesired amplitude and prohibited frequency modulation that could be caused by otherwise changing loads on the transmitter are reduced to a minimum. In the present design, amplitude modulation does not exceed a ratio of two to one over each cycle of piston movement; and frequency modulation is in fact negligible.

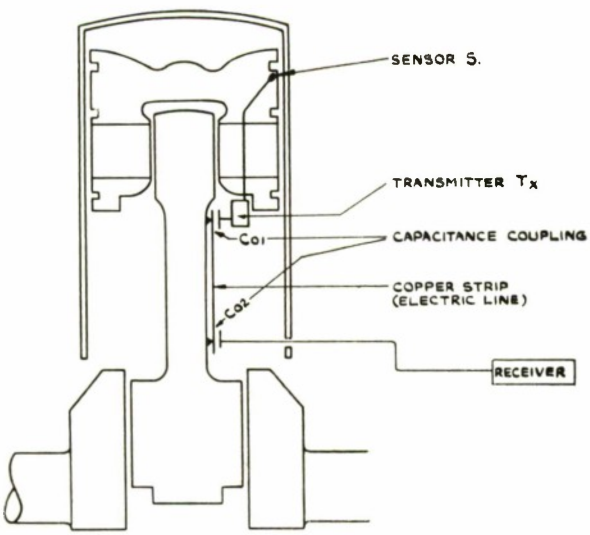


FIG. 1. Basic Assembly.

The sensor's temperature may be read at any time, in terms of frequency, by tuning the receiver to the incoming signal. Temperature changes, if slow, may be followed directly by manual tuning of the receiver. However, as changes in the sensor parameter may be fast, particularly in the case of the projected displacement measurements, the received signal frequency was converted to an analogue and recorded.

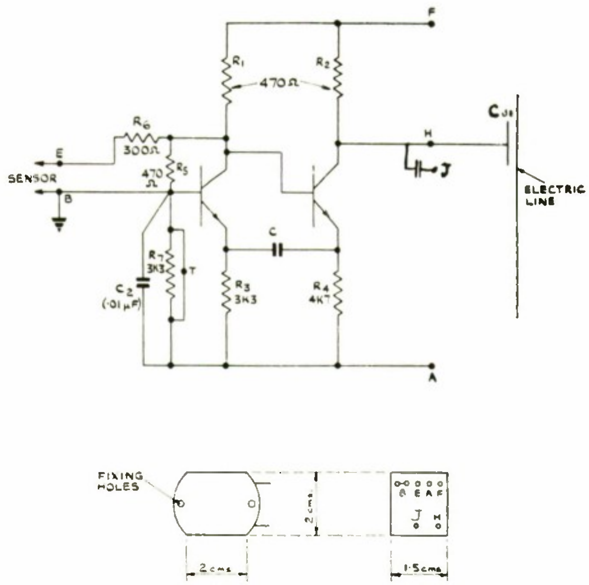


FIG. 2. Transmitter (one Channel) Circuit Diagram and Physical Dimensions.

For multichannel operation the electric line is common to all channels, individual selection being effected in the receiver by appropriate 1 mc/s bandwidth filters (Fig. 4). Undesired inter-transmitter interference is prevented by appropriate RC filtering applied individually to all transmitters.

The Transmitter

The requirement for small dimensions considered together with the adverse conditions under which the transmitter would be operating precluded the usually applied methods for attaining frequency stability *i.e.* tuned circuits or crystals maintained at a constant temperature. Also the prospect of employing automatic frequency control in the receiver seemed to bristle with uncertainties. Instead, a circuit was chosen that could meet what is, after all, the basic requirement, *i.e.* a large ratio of signal frequency sweep of the transmitter to undesired frequency shift during the prevailing temperature variation, *viz.* 20 to 100°C, special care being taken in the design to stabilize the transmitter—as far as possible—in its own right. The final circuit is shown in Fig. 2.

Two silicon transistors and micro-miniaturised low temperature coefficient resistors (50 p.p.m.) are welded rather than soldered together in a switching type of RC circuit. Only one condensor with linear temperature characteristics is included in the frequency determining part of the RC circuit in order to ease the approach in the design for frequency/temperature stability. The circuit is essentially an emitter coupled multivibrator[8] whose frequency f is given approximately by

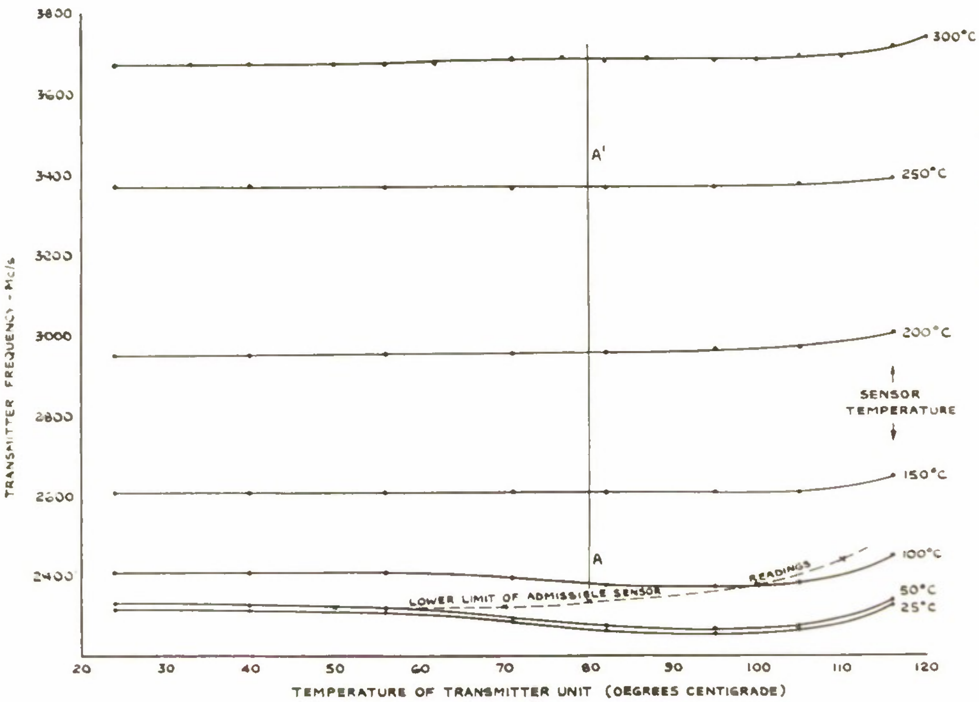


FIG. 3(a). Transmitter characteristics. Frequencies for constant sensor temperatures up to 300°C.

$$f=\frac{1}{2}\frac{R_3+R_p}{CR_p(R_3+R_4)}, \text{ where } R_p=\frac{R_1\ R_5}{R_1+R_5}$$

i.e. R_1 and R_5 in parallel (sensor disconnected) or

$$f\simeq\frac{1}{4CR_p} \text{ if } R_p << R_3 \text{ and } R_4, \text{ and } R_3 \simeq R_4$$

From this it follows that the transmitter frequency can be conveniently controlled (by large amounts) by varying thermistor shunts across R_5 or R_1.

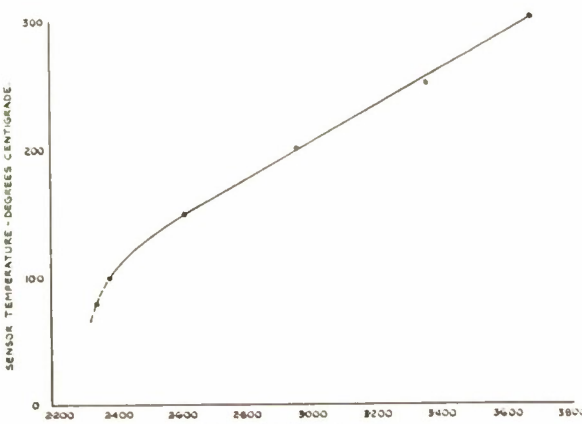
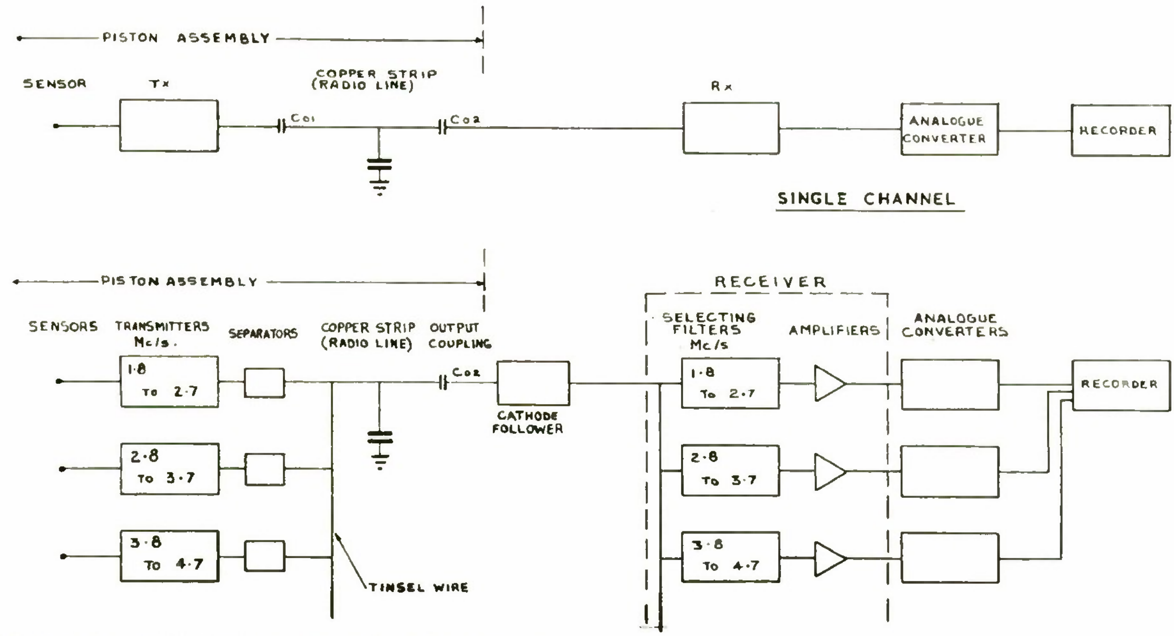


FIG. 3(b). Calibration:—Frequency against Temperature Transposed from Fig. 3(a).

A more accurate analysis would show that the frequency is, to some extent, dependent upon the supply voltage, the aerial loading and, of course, on the transistor's temperature. However, an adequately stable frequency can be maintained (R_p constant) throughout the temperature range of the transmitter environment by keeping the supply voltage constant at around 5 volts, ensuring that the aerial loading is fairly constant throughout the engine cycle and balancing out the effect of the temperature variation with an auxiliary thermistor device, T, connected between base and emitter. This auxiliary thermistor is included in the completely encapsulated unit. To all intents and purposes, all three requirements have been met in the design. In Fig. 3a, transmitter frequency versus its temperature has been plotted for a series of constant sensor temperatures. Ideally these lines would be horizontal. Temperature increments of the thermistor (sensor) environment are given, in terms of transmitter frequency, by interception on any vertical line. For example, the vertical line 'AA_1', transposed on to Fig. 3b, gives the calibration when the temperature of the transmitter is 80°C; and there is no significant change in the calibration, for any other temperature value of the transmitter. The consumption per transmitter unit is 5v × 3mA.



FIGS. 4(a) and (b). Single and multi-channel schematics.

Possible Displacement Sensor

For displacement measurements, preliminary work has shown that a tuned circuit shunted across R_5 or R_1 can give adequate control over the transmitter frequency when its dynamic impedance is altered by proximity of metal to the inductance of the tuned circuit. The high frequency used for the transmitter permits the employment of a small value of inductance. In an actual experiment a small probe consisting of an air cored coil of 50 microhenries, tuned to the transmitter frequency by an auxiliary condenser, produced a frequency sweep of 150 kc/s when the plane of a metal plate was moved toward the coil's end face through a distance of 0·015 in. when using a 3 mc/s carrier.

The presence or absence of oil in the gap had no effect on the frequency.

Direct relative displacement measurement under cyclic movement of the piston during normal engine operation are thus feasible, but absolute measurement would not be—other than by interpolation—on account of the impedance/temperature-coefficient of the probe itself which is likely to be too large to be ignored. However, the absence of an iron core will facilitate the design which, it is visualised, will require that the coil be buried or encapsulated in ceramic material.

Block Schematics

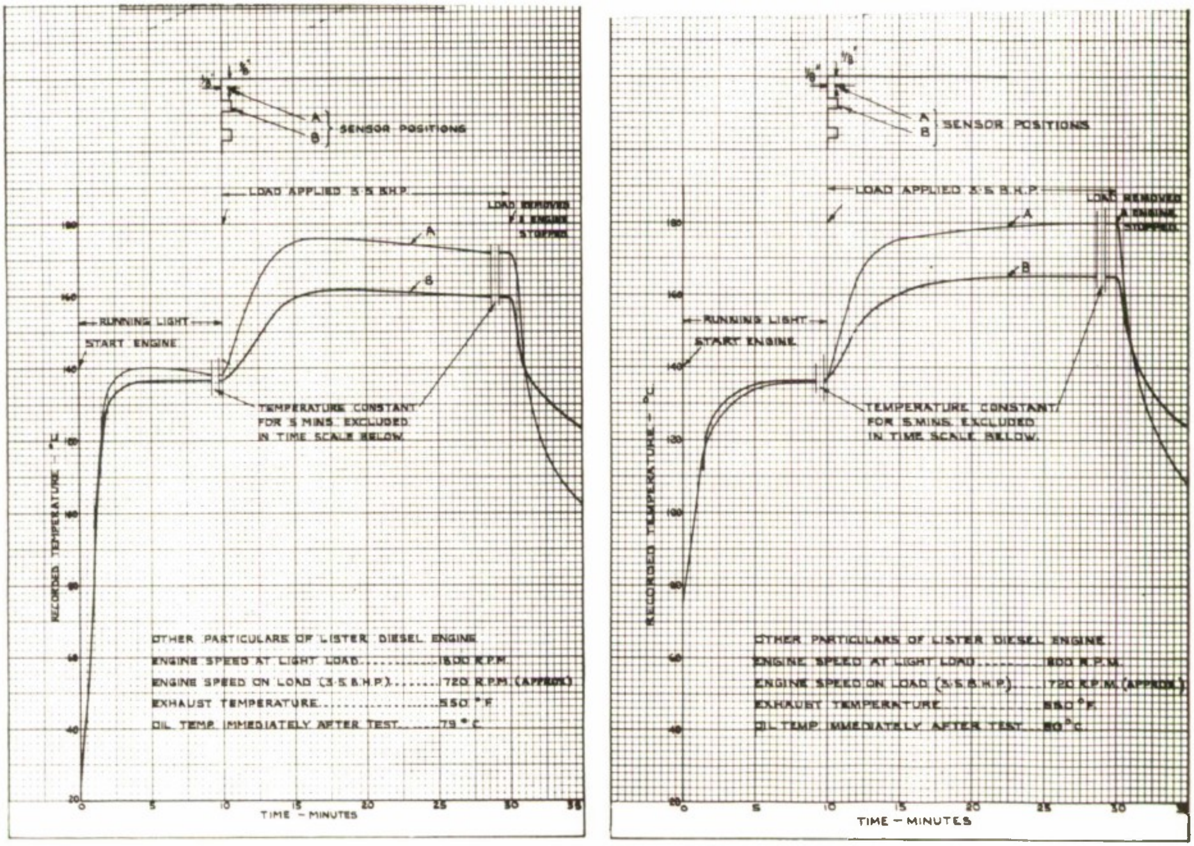
A block schematic for single channel operation is shown in Fig. 4a.

For multichannel operation, Fig. 4b, a low pass filter acting as a separator is inserted between the output of each transmitter and the common radio line coupling to prevent interference between transmitters. This reduces the output from each transmitter, but by this simple means this interference is reduced to a low enough level as to be of negligible significance. The signal strength is subsequently more than retrieved with elimination of the high impedance coupling capacitance C_{01} by using the tinsel wire connection referred to later.

At the receiving end, channels are selected *via* appropriate filters and the signals converted to analogue values for direct recording.

Experimental Work and Results

Sensitivity. Two transmitters with ranges 1·8 to 2·7 mc/s and 2·8 to 3·7 mc/s have been built. The characteristics of an earlier unit tested on the bench, are shown in Fig. 3a. The two transmitters have equally good characteristics but they are not reproduced here. A sensitivity of approximately 7 kc/s per degree centigrade is indicated for thermistor temperatures between 150°C and 300°C,



(a) Two channel operation. (b) Separate channel operation.

FIG. 5. Telemetered temperatures during trials under start, light and full load conditions.

and an estimated overall measuring accuracy of $\pm 2\frac{1}{2}\%$ is anticipated.

Intermodulation Interference. Apprehension that interchannel intereference might nullify the system for general use was soon dispersed. Preliminary tests on the bench with both transmitters fitted on a piston, temporarily removed for the purpose from a Lister engine, showed that intermodulation interference between two adjacent channels had been reduced to an insignificant value by the transmitter output filters and the receiver selecting filters.

The inconvenience of providing more than one temperature environment on the bench, *i.e.* one for the transmitters and others for the thermistors, was overcome by simulating the thermistors at specific points in the desired range of temperature measurement up to 300°C with a number of resistances that could be switched into circuit in turn. Thus only one changing temperature environment was required for the transmitters up to 100°C. In no case did either transmitter when treated as an interfering source produce a change exceeding 1 kc (0·2°C) in the frequency of the desired signal.

The piston assembly was then refitted in its engine and connected to temperature probes sited (a) near the perimeter of the crown and (b) just inside the upper groove base. The results for half hourly runs which included start, light and full load conditions are shown in Figs. 5a and 5b, the former for simultaneous operation of the two channels and the latter for separate operation.

The temperature rise times soon after starting and soon after applying the load are confirmed, but during the subsequent ten minute settling down period, there is a slow drop in Fig. 5a and a slow rise in Fig. 5b. This is believed to be due to slightly different running conditions leading to different thermal distributions in the engine and in the transmitter units themselves. Regarding the latter, small monolithic designs of stable transmitters may shortly become available so that transient temperature differentials between internal components of the transmitter, that occur during a rapidly changing heat condition, will not have a significant effect of the frequency measurement.

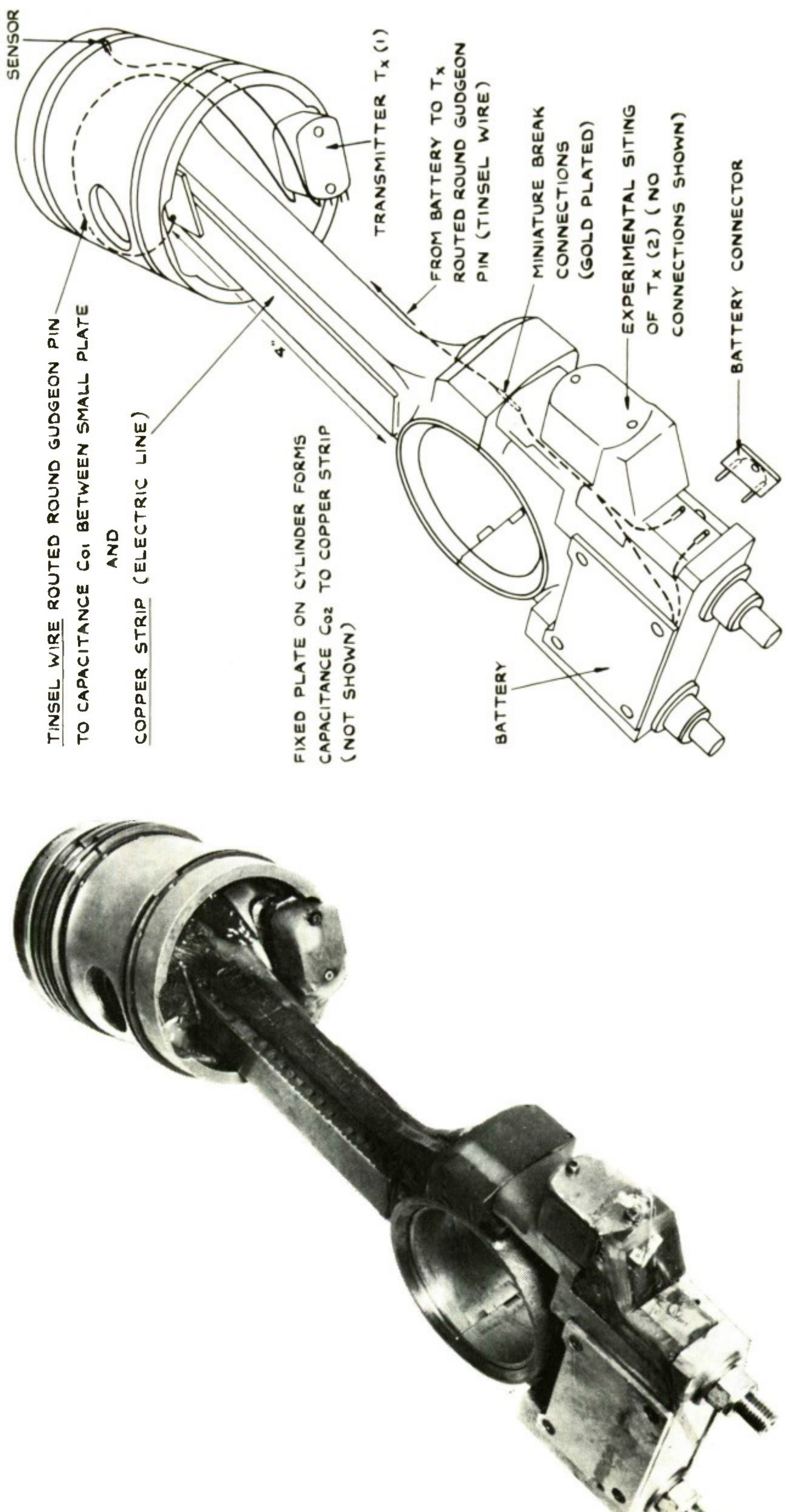


Fig. 6. Layout of Single Channel Transmitter System.

Mechanical Strength, Signal Stability and Battery Capacity. The transmitter units—fitted in the Lister engine—withstood the forces encountered under light and full load conditions estimated, from stroke and RPM considerations, at ±200g. One of the transmitters was, in fact, finally fitted on the base of the con-rod where it also experienced an impact force during every engine cycle, when plunging into the sump of hot oil.

In the original design it was intended that the transmitting part of each channel consist of a "throwaway" probe complete in itself *i.e.* containing the sensor, the transmitter and its own small battery. But it was soon established that the techniques at elevated temperatures were not, and still are not sufficiently well known to warrant this forward step. Instead it was decided to fit one transmitter on the piston underskirt, one on the con-rod, and the batteries for both in a housing fitted to the con-rod base. This would demonstrate possible optional sitings for these components.

The problem of flexible connections between components on the piston and their counterparts on the con-rod was solved by the use of copper tinsel wire insulated with PTFE tubing—always routed round the gudgeon pin. The PTFE tubing was anchored to frame near the ends where the tinsel wire emerged. This proved highly successful; and, to demonstrate the durability of the tinsel wire some of the leads were duplicated, routed round the gudgeon pin, connected in series, and the engine operated for a period of five hours without the necessity for lead or component replacement.

During this test one of the transmitters was kept under close observation for stability. The frequency did not change by more than 5 kc/s *i.e.* 1°C.

The power supply consisted of a battery of four Type RM625 RT Mallory cells connected in series. The maker's characteristics indicate an operating time of 60 hours for one channel, 30 hours for two channels and *pro rata* for more channels but with less voltage frequency stability.

Further Development

It is intended to develop the system to enable eight parameters to be observed simultaneously which must also cater for displacement measurement. The only type of sensor that can be visualized at present for detecting movement in an oil atmosphere and under high temperature conditions is a small multilayer coil embedded in ceramic. The choice of high frequencies in the present system permits the use of a small value of inductance and without an iron core. The inclusion of an iron core would impose an upper limit, determined by the Curie point of the material, on the permissible measuring temperatures; and manufacturing difficulties have yet to be overcome in the use of ferrous materials for transducer at 250°C upwards[5].

Although the present design of transmitter unit is quite small, it is considered that, if one were produced using thin film or integrated circuit techniques, then thermal delays between its constituent components would be reduced with a consequential improvement in measuring accuracy.

Conclusions

A system of telemetering information from piston engines using frequency modulation of carriers in the band 1 to 10 mc/s and occupying 1 mc/s per channel has been described and proved for two channels as regards temperature measurement. Outstanding items of which details are given in the text area:

(a) A micro-miniaturised transmitter, adequately stable in frequency in its own right throughout the working temperature range, 20 to 100°C, and capable of being directly modulated by a thermistor sensor up to 300°C or more to give an estimated temperature measuring accuracy of $\pm 2\frac{1}{2}\%$.

(b) An arrangement for the non-contact coupling of components from the piston *via* the con-rod to an external receiver.

(c) A simple flexible lead system consisting of tinsel wire in PTFE tubing for connecting components on the piston to those on the con-rod.

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Icebreaker and supply ship in McMurdo Sound.

MODERN MAN AND EQUIPMENT IN ANTARCTICA

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Introduction

Man with his modern equipment commenced large scale operations in Antarctica during 1956 in preparation for the International Geophysical Year. These operations have continued and have been reinforced by more proven equipment, much of which has been considerably modified to meet specific requirements that such operations demand.

In the 14 million square kilometers that comprise Antarctica the most severe and variable climatic conditions on earth are found. Combined with extremely difficult terrain such conditions create logistic problems men have not been faced with before, thus logistic requirements and methods of support must be modified accordingly.

Man's toughest enemy in Antarctica still remains the unpredictable climate. Not so much the cold, but the long periods of strong winds that bring blizzards, blowing snow and whiteouts. In such conditions man and his equipment become completely immobilized, sometimes for weeks on end. Thus, in planning of field operations considerable excess time must be allowed to safeguard the operation against this weather factor.

In the comfort of established bases man's greatest danger is one of his own making—fire. Fire is still the greatest single hazard in Antarctica, where the cold but exceptionally dry climate dehydrates building materials and equipment; high winds are prevalent, considerable amounts and types of internal heaters are used, and drifting snow in covering buildings, also blocks doors, windows and escape hatches, thus creating a real fire trap.

If man was lucky enough to escape disaster he would certainly be in a serious situation in possibly being without shelter, adequate clothing, food or warmth. It is essential that all measures be taken to prevent fire and fight it, and if at all possible to have alternative emergency shelter and food available within reasonable distance.

Modern equipment has not solved many living or operational problems in Antarctica, in fact to a great degree has only added to what is still nature's greatest challenge to man, and although man has accepted this challenge and adapted himself quite readily to the Antarctic environment, he has far from conquered the numerous problems and hazards that exist.

Icebergs. Black dots in foreground are seals.

Climate

Any Antarctic operation can prove hazardous at any time of the year. The normal cold conditions can usually be overcome by simple adequate clothing, but extremely rapid changes in weather conditions increase the large wind/chill factor and often cause whiteouts, blizzards and zero visibility. Fine particles of blown snow are extremely penetrating and often bury vehicles and equipment, cause large snow drifts and extremely soft surface conditions.

Temperature range is extensive, from nearly −130°F during mid-winter in the centre of the Polar Plateau of East Antarctica to +40°F at coastal stations during summer. Latitude affects temperature to only a minor degree, distance from the coast and elevation are the major contributing factors in lower temperatures.

Snowdrift at Scott Base.

Precipitation in the interior of Antarctica is small, averaging under 10 c.m. annually, for here high elevations and cold temperatures preclude the conditions required to produce heavy snow. In these areas accumulation is caused by blowing snow and to a lesser degree by precipitation due to ice crystals (frozen air).

Most coastal areas inland for some 250 miles receive a great deal of snow, particularly in summer when warm moist air from the north penetrates into the Antarctic regions. Overcast weather causing whiteout conditions also persists during this period. Accumulation in some coastal areas is as high as two metres annually.

Wind also varies considerably with location. In the interior (South Pole-Vostok area) highest wind speeds recorded are in the vicinity of only 25 knots. Coastal areas commonly experience winds exceeding 100 knots, often nearing 150 knot gusts and quite possibly exceeding those figures in many areas where meteorological data have not been recorded.

These severe conditions also impose serious restrictions on construction personnel, materials and equipment. It is essential that prefabrication be used to its fullest extent and that the simplest possible methods of well planned construction be followed.

Effects of Extreme Sub Zero Temperatures

The coldest temperature experienced on earth has been recorded at Vostok, the USSR Base near the centre of East Antarctica. In August 1960 a temperative of −126·9°F was recorded. The question of how man and his equipment can operate under such low temperatures is a complex one.

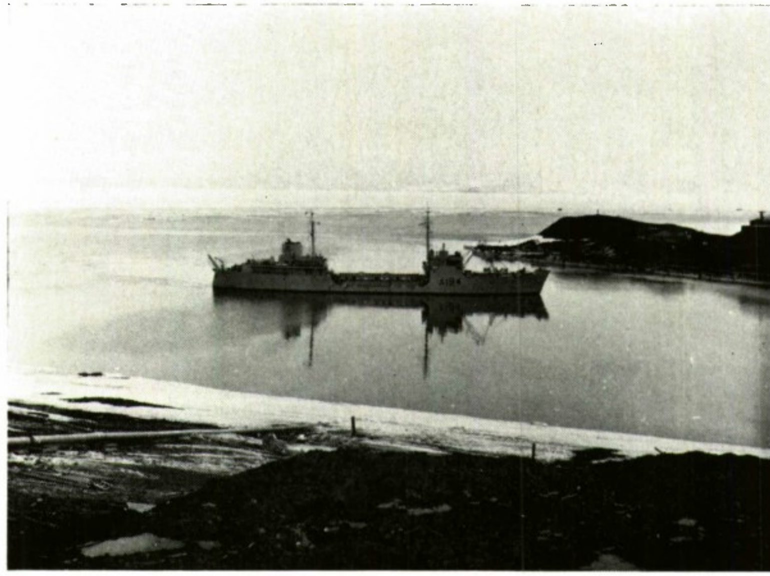
Man, adequately clothed, can remain reasonably comfortable in temperatures down to approximately −60°F (this is not allowing for any wind and subsequent "wind-chill factor").

Most mechanical equipment (modified and specially protected for cold conditions) can operate reasonably well down to temperatures of approximately −50°F.

This temperature (approximately −50° to −60°F) could be classified as the "Cold Barrier", and to break through entails more than special equipment and clothing. For instance:—

(a) Natural rubber becomes hard and brittle at −50°F and insulated cables cannot be moved without fear of losing their insulation, and rubber tracked vehicles become immobilized.

H.M.N.Z.S. Endeavour near Hut Point, McMurdo Sound, December 1965.



(N.B. Synthetics and plastics are not recommended for use in Antarctica as they harden at only a few degrees below freezing.)

(b) Lubricants, oils and most fuels have long since thickened considerably or frozen completely.

(c) Metal fatigue and fracture is commonly experienced.

(d) Man becomes an easy victim to severe frost bite. Artificial means of heating body extremities and air to be inhaled are necessary and problems such as eye-lids freezing shut and difficult breathing due to accumulation of exhaled air forming ice on the face present serious difficulties.

In an attempt to overcome these problems, various blizzard masks have been designed but none has proved completely successful. This is mainly due to exhaled air forming ice in the vents and cutting off the supply of air.

Perhaps the most successful is a Russian designed mask which is made from plexi glass into which is moulded a number of heater wires powered from alkaline nickel cadmium cells carried in a special container slung around the waist. These provide quite adequate protection and warmth but can only be used effectively for a limited time due to the limited capacity of the battery.

Terrain

Over 95% of the surface of Antarctica consists of snow or ice in a number of forms.

The remainder is exposed rock most of which is the high peaks of mountain ranges or peaks of isolated mountains protruding through the high elevation of accumulated snow and ice. Most of these rock, moraine, and ice free areas are located in the Ross Dependency and on the Antarctic Peninsula.

The snow or ice surface presents serious problems to surface travel, particularly to vehicles. Most coastal and glacial areas are heavily crevassed. Crevassed areas are always associated with ice movement and although the conditions likely to cause crevassing are usually recognisable, crevassing can be well camouflaged by a deep covering of soft snow.

In good visibility these crevasses can be recognised by a slight change in colour compared to the surrounding surface, then positive locating can be achieved by probing.

Sastrugi (snow drifts, compacted and hardened by winds) up to two metres high, also makes surface travel by vehicles extremely difficult and can be a real hazard to landing aircraft. Sastrugi in varying sizes exist in most areas, increasing in size where large snowfalls, constant winds (both direction and speed) and fully exposed surface are combined.

Many areas (usually coastal with extremely high precipitation) present extremely soft snow conditions. This soft surface appears near "bottomless" and makes for great difficulty in walking and immobilizes all present known forms of surface transport.

The surface of ice shelves (particularly the Ross Ice Shelf) and sea ice usually offer reasonable surface for transport operations and for aircraft runways. Crevassing however is most extensive where glaciers and ice falls feed an ice shelf, thus caution must always be taken where ice shelves or sea ice nears the coast.

Clothing

In the days of early exploration it was thought that any type of clothing if heavy enough would provide the necessary warmth.

To-day's proven clothing is light and windproof, allows freedom of movement with adequate protection for the wearer. New Zealand experience with light windproof material has proved *Wyncol* to be most suitable. This is a cotton nylon woven combination. For extreme cold conditions, down has been used as an insulation in jackets and trousers covered by *Wyncol*. Although somewhat bulky, lightness and freedom of movement is still achieved. It has been found that a number of lighter garments have more advantages than a few thicker and/or heavier garments. Lighter garments can be discarded to adjust the amount of warmth and protection required. Wearing one heavy garment may overheat the user, but if discarded he would become over-exposed to the cold.

The extremities of the human body pose problems in providing adequate warmth, comfort and movement. Gloves are useless as they restrict the circulation and place cold barriers between the fingers. Greasy wool mitts with an outer mitt of either windproof material or leather are best. Under extreme conditions the leather outer should be lined with lambswool and have an outer coating of fur.

No complete answer can be given to a suitable type of footwear for use under all conditions. Personal preference usually determines the type worn. Undoubtedly, this preference has been for Mukluks as these are most comfortable, can be worn

Mukluks, showing all inners and outer.

Typical Antarctic Clothing.

Antarctic Underwear.

A selection of Gloves and Mitts.

under all conditions (except wet), and if worn with sufficient inners they provide reasonably adequate protection even under most extreme cold conditions.

String knit underwear has proven advantages and is recommended. Circulation of an air layer around the body permits an added heat circulation system, and combats the bad effects of excess perspiration.

Ski caps and balaclavas have both been used with success as they can be designed to fit low around the neck and also provide adequate protection to the ears.

Dog teams about to board aircraft.

Vehicles

Numerous types of vehicles have been used for surface transport in Antarctica, ranging from the light man-hauled sledges to heavy tracked vehicles. No vehicle has been able to cope with all transport requirements nor fully overcome the variety of difficult terrain.

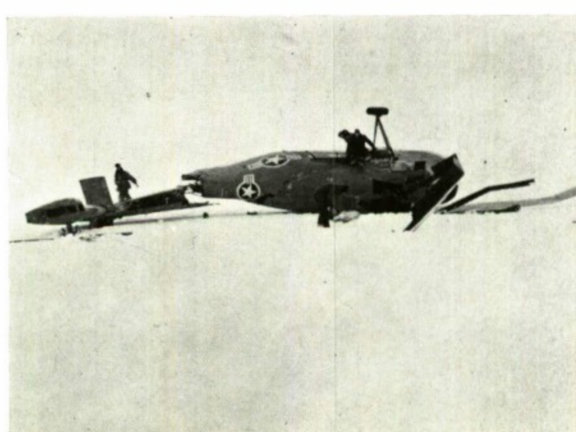
Steel tracked vehicles (particularly as prime movers) have proved superior to all other types of traction, the track plates being made sufficiently wide to achieve a reasonably low ground pressure.

Rubber tracks with steel cleats are generally quite suitable for lighter vehicles. Their greatest disadvantage is their limited life through their susceptibility to hardening and consequent cracking when used in extremely cold conditions.


Top of DC3 aircraft buried in snow following a winter at Scott Base.

Wheeled vehicles have been used with some success. On hard sea ice, snow surfaces, and snow free areas, low pressure sand tyres combine good traction with reasonably low ground pressure. Wheeled vehicles are not at all suited for softer conditions existing on the Polar Plateau.

A recent addition to the types of over-snow vehicles is the Polaris Motor Toboggan. Of simple, light construction and powered by a four-stroke petrol engine driving a cleated nylon reinforced driving belt, the toboggan permits ease of operation with minimum maintenance. It is capable of speeds up to 10 m.p.h. over most surfaces carrying two men and pulling a sledge load of over 1,000 lb. Thus it is ideal for light field use and reconnaissance purposes.


Helicopter crash during white out.

Although terrain is the greater problem met, other extreme difficulties have to be overcome. Metallurgical problems which are considerably increased with lower temperatures cause metals to become brittle and fracture, contraction of metals causes welds to break, thus breakdowns and maintenance time increases considerably. Difficulties of starting requiring long hours of pre-heating, lubricants and fuels becoming solid, failure of electrical systems, electrical breakdowns due to hardening and failure of insulation, inadequate coolants, additional altitude compensation for carburettors

A selection of vehicles parked at Scott Base.

Caterpillar tractor in a small crevasse.

Swedish built Snow Trac and Volkswagen with skis.

and fuel injection systems, are all problems only too common to the Antarctic traveller.

Repairs of any mechanical failure, due to the extremely difficult outside working conditions can generally be calculated to take three to four times longer than in a normal heated workshop.

New Zealand experiences with a wide variety of over-snow vehicles puts the average maintenance time as high as one hour maintenance for one hour actual operating time.

Conveying of loads is achieved by either sledges or trailers. Trailers (usually with large low pressure tyres) are only suited to harder surfaces and as in the case of all wheeled vehicles are not suited to the softer conditions of the Polar Plateau. Thus wheeled trailers have a restricted use only.

Sledges are quite adequate on all snow surfaces and numerous sizes and designs are used. In determining the type of sledge for a particular job, consideration must first be given to the power and traction of the prime mover, the weight and cube of cargo, and terrain to be encountered. It is good policy to use a number of light sledges rather than one or a few heavy sleds as even with a large prime mover a heavily laden large sledge when bogged down in soft conditions becomes a major problem.

In all vehicle operations the most important factor is simplicity. Maintenance time is high and working conditions most difficult. Complex equipment will only add to all these problems.

Heating

At all Antarctic stations the commonest source of heat and power is diesel oil. Diesel electric generators at New Zealand's Scott Base provide both power and heat; power from the generators and heat *via* heat exchangers in the exhaust system of the Diesel Engines and from air heated *via* a forced draft system through the radiators of the diesel. Electric heaters are not used to any extent as this indirect method of using diesel oil is most uneconomical and the capacity of generators is limited.

Best direct use of fuel is by using oil burning, heat exchange system of electrically fired, forced draft heaters. This is the type installed at Scott Base (Trade Name *Waterbury*. Capacity 100,000 B.T.U. per hour) which has proved most effective. Each hut has a separate unit and the warm air is distributed throughout the area *via* ducting, thus achieving an even heat distribution.

Heating of vehicles is usually achieved by a smaller version of this type of heater. Fuel used is gasoline, fired by a glow plug and forced draft supplied by fans through both circulating systems of the heat exchanger. Such units are capable of providing 25 - 30,000 B.T.U. per hour which is quite sufficient to keep the interior of an average

sized vehicle at a reasonable temperature even when subject to the coldest of Antarctic conditions. Adequate vehicle heat however will cause severe icing of windowscreen and windows. Often the interior/exterior temperature difference may be 140°F though a thickness of only ¼ in. armour plate glass. Under such conditions, falling or blowing snow will form ice on the glass and restrict vision. Direct heat must be applied to the glass

A motor toboggan.

to prevent this situation. This can best be achieved by having a section of heating wire held between two plates of glass that form the windscreen where required to provide the driver with adequate vision. Such a heater will require approximately 30 watts of power to warm and thus keep clear an area of 80 sq. in.

Preheating of vehicles and equipment is a most necessary but difficult task. The *Herman Nelson* gasoline fuelled heat exchanger type heater, the fans of which are powered from a four-stroke gasoline motor has proved most efficient and operates quite well in temperatures as low as −80°F combined with elevations exceeding 12,000 ft.

The 100,000 B.T.U. per hour of heat generated and circulated *via* this forced air system can be applied directly to vehicles and equipment *via* large diameter flexible hose. Adequate covers for equipment to minimise heat loss should be provided.

Large flame throwers have been used with only limited success. Under very cold conditions the inrush of cold air is sufficient to cool the jet surround to such an extent that ignition fails and the flame is extinguished.

Heating of caravans, wannigans, small huts, and for field work generally, can be achieved by use of butane gas. Some of the advantages being, little preparation, quick heat, clean burning with air/gas adjustment, still burns well at elevations in excess of 12,000 ft. not subject to much pressure loss under cold conditions, gas is available in a variety of containers (some dispensable) and also gas can be used for purposes other than heating, *e.g.* cooking, lighting and light welding.

Major Logistic Problems

The Antarctic Continent has no close neighbours and it does not support much life to provide food for man, nor has fuel been found for heating, equipment operation and power generation. Thus all food and fuel requirements must be transported in.

The supply of fuel is the largest single logistic problem in Antarctica. It is usually delivered in bulk form by ship to the coastal stations where it is either pumped into large steel storage tanks or into 10,000 gallon neoprene bladder tanks.

These flexible tanks have been used quite successfully even when laid directly on snow or ice, thus little effort is required for installation.

Helicopter near Balleny Islands.

Fuel for inland stations is supplied in drums either delivered by tractor train or aircraft from a coastal station. Tractor train is slow and damage to drums considerable due to rough terrain. By aircraft, costly in fuel for the aircraft itself and if air drop methods are necessary, costly in excessive damage and loss in deep snow.

COMPUTER-TYPE STORES FOR SORTING DATA FILES ON A QUANTITATIVE OR ORDINAL NUMERICAL BASIS

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SUMMARY

Many data-processing systems maintain records concerning the members of a statistical population. We may then wish to find those members for whom one of the recorded items is within set limits of a given numerical value, or we may wish to find the n^{th}—or say the first n—in order of (non-uniformly) increasing value of some parameter. This paper is concerned with the design and use of efficient catalogue cross-reference systems for the economic and versatile solution of this class of problem in computer-type data processors. An Appendix singles out the field of air-traffic control to illustrate the variety of practical functions for which such numerical sorting is of value.

Introduction

Data-handling systems, both on-line and off-line, commonly involve a data file, recording information concerning a given statistical population. A common standard format is then used for storing the relevant data concerning each member of this population. (See Fig. 1a). Normally most of these data are in numerical form, and even if the eventual output required is only *comparative* (bigger, smaller, equal), or *ordinal* (first, second, n^{th}, last), it is normally best to start with *quantitative* information in the form of cardinal numbers.

There are thus numerous operations for which it is desirable or indeed essential to select those members of the population for whom a given file entry has a particular value or lies within given limits of cardinal or ordinal value. The Appendix lists some representative hypothetical applications, from the fields of plot compilation and traffic management for air-traffic control. Equally pertinent applications could have been found in population censuses, staff records, stock control, credit accounts, reference libraries, operational analysis and numerous other fields.

The Design of Efficient Cross-Reference Catalogues

Normally the members of the statistical population will have been entered into the main file in a sequence unrelated to the value of the particular parameter of current interest (See Column 2 of Fig. 1a), and a search through the whole population is an uneconomically lengthy procedure. Such a search can however be avoided if, at the time of entering a population member in the main file, its file number is also recorded in a *catalogue* (See Fig. 2), listing members in accordance with the value of the quantity of interest.

We can lay down certain guide-lines for the construction of such catalogues:—

(i) If a catalogue heading covers an excessively wide bracket of values, a time-wasting search through the entries under this heading may be required. Hence finer sub-division of the classification may be desirable. The coarse and fine divisions may then be distinguished by two or more stages of branching, as illustrated in Fig. 3a.

(ii) However, empty catalogue pages are wasteful; hence each catalogue heading or sub-heading should cover a bracket of values large enough that it can be expected to attract one or more entries.

(iii) If requirements (i) and (ii) appear to conflict, *separate* overall catalogues may be constructed for the "coarse" and "fine" digits of the relevant quantity (See Fig. 3b). Indeed the bracket of values of the given parameter may be represented by three or even more significant digits, on an appropriate number scale, with a separate catalogue for each digit position and a separate catalogue page for each discrete value of each digit. The individual (digit-value) catalogue headings may then be wide enough to attract sufficient entries, even with very non-uniform population distributions. At the same time, the selectivities of several digits may be combined, by suitably "compounding" the catalogue data, to achieve a very fine resultant selectivity.

Main File Serial No.	'Members' Details			
	A=	B=	C=	D=
1	2	1	–	–
2	3	2	–	–
3	2	1	–	–
4	4	1	–	–
5	3	2	–	–
6	1	1	–	–
7	2	2	–	–
8	2	2	–	–
9	3	1	–	–
10	1	2	–	–
11	2	1	–	–
12	3	2	–	–
13	1	2	–	–
14	2	1	–	–
15	4	2	–	–

FIG. 1(a). Main File.

Serial Nos. for same 'A'	
Preceding	Following
–	3
–	5
1	7
–	15
2	9
–	10
3	8
7	11
5	12
6	13
8	14
9	–
10	–
11	–
4	–

FIG. 1(b). Distributed Catalogue.

A=	Main-File Addresses
1	6, 10, 13
2	1. 3, 7, 8, 11, 14
3	2, 5, 9, 12
4	4, 15

FIG. 2. Simple Catalogue.

High-Significance Digit		Main-File Addresses	
		A=1 or 2	A=3 or 4
Low Significance Digits	A=1 or 3	6, 10, 13	2, 5, 9, 12
	A=2 or 4	1, 3, 7, 8, 11, 14	4, 15

FIG. 3(a). " Coarse-and-Fine " Branching Catalogue.

Digit Significance	A=	Main File Addresses
Low	1 or 3	2, 5, 6, 9, 10, 12, 13
	2 or 4	1, 3, 4, 7, 8, 11, 14, 15
High	1 or 2	1, 3, 6, 7, 8, 10, 11, 13, 14
	3 or 4	2. 4, 5, 9, 12, 15

FIG. 3(b). Coarse-and-Fine Twin Digit Catalogue.

A=	*B=*	*Main-File Addresses*
1	1	6
	2	10, 13
2	1	1, 3, 11, 14
	2	7, 8
3	1	9
	2	2, 5, 12
4	1	4
	2	15

FIG. 4. Twin Parameter Combined-Catalogue.

(iv) To economise in catalogue storage (and in the "compounding" of multiple "digit" catalogues), the number of discrete catalogues (each covering *all* members of the population from a different point of view) should be minimised. This will also minimise the load of keeping the catalogues up-to-date.

(v) Hence the separate digit catalogues of expedient (iii) should be used no more than essential.

(vi) Indeed, if criterion (ii) is well satisfied (*i.e.* if there are normally plenty of entries under each catalogue heading), two independent statistical quantities may be combined in one catalogue, the discrete value-brackets of the second forming sub-headings in the catalogue pages of the first. (See Fig. 4). For instance we may be interested in two quantities X and Y, each divided into value brackets 0 to 9. If the catalogue page for X=3 would be expected to have about 20 entries, we could further sub-divide this into (X=3, Y=0), (X=3, Y=1), (X=3, Y=2) . . . (X=3, Y=9), with an average of two entries per sub-heading. To select all population members giving Y=2, we would then combine the entries from (X=0, Y=2), (X=1, Y=2), (X=2, Y=2)..., one each from the catalogue pages for X=0, X=1, X=2 . . . Similarly three or more quantities may be combined on one catalogue page, with successive stages of sub-division, when appropriate.
This technique is of special value if a search for population members in given regions in the combined X and Y "plane", or other generalised "multi-dimensional space", may be operationally required. See also later comments.

Economical Catalogue Storage for Populations of Variable Density

When the number of entries under each catalogue heading is very variable, it is wasteful of storage space to allocate a catalogue page of fixed size to each catalogue heading. In this case it may be preferable to divide the store into blocks (or "paragraphs") of intermediate size. Each catalogue heading could then have a further block of storage space allocated to it from a common "pool" (See Fig. 5c), when it has filled its last block, and each catalogue heading would restore a block to the central pool when it has cleared the last entry from that block. The storage blocks associated with one catalogue heading would not normally be consecutively numbered in the catalogue store. A catalogue index would thus clearly be required, to indicate the blocks associated with each catalogue heading. It might be convenient if this index indicated the location of the last entry within the (partially filled) block currently "in use", although it should not be difficult to search for this, since the block would be designed to be reasonably small. (See Fig. 5b).

A=	*Block No.*	*Main-File Addresses*	
1	1	6	10
2	2	1	3
3	3	2	5
4	4	4	15

5(a) Pre-allocated Blocks

Further Data in Blocks No.		*Places Filled in Last Block*
5	–	1
6	7	2
8	–	2
–	–	2

5(b) Associated Index

Block No.	*Main-File Addresses*	
5	13	–
6	7	8
7	11	14
8	9	12
9	–	–
10	–	–

5(c) 'Spare' Block Pool

FIG. 5. Catalogue with Adjustable Capacity.

A=	*Block No.*	*Main-File Addresses*		*Next Block No.*
1	1	6	10	5
2	2	1	3	6
3	3	2	5	8
4	4	4	15	–

6(a) Pre-Allocated 1st Blocks

No. of Extra Blocks	*Last Block No.*	*Places Filled in Last Block*
1	5	1
2	7	2
1	8	2
–	4	2

6(b) Associated Optional Index

Block No.	*Main-File Addresses*		*Next Block No.*
5	13	–	–
6	7	8	7
7	11	14	–
8	9	12	–
9	–	–	–
10	–	–	–

6(c) 'Spare' Block Pool

FIG. 6. Catalogue with Distributed Index.

Note.—The Main File of Fig. 1a is common to all diagrams.

It would also be possible to *distribute the Index* by recording, at the beginning of each block, the identification number of the preceding block for the given catalogue heading and storing, at the end of the block, the identity of the next block. (See Fig. 6). A pre-determined allocation of " first " blocks could then remove the need for any catalogue index. However it would probably be useful to retain a concise index giving for each parameter value:—

(i) the number of blocks used
(ii) the block identity, and position within the block, of the last entry under the given heading.

It would be possible to *distribute the catalogue* itself, by storing in the main file, in association with the given parameter, the addresses of the preceding and following main-file entries for which this parameter comes under the same catalogue headings. (See Fig. 1b). In this case the catalogue index would only record the main-file address of the first and last entries under the given catalogue heading, and possibly the total number of such entries. (See Fig. 7). The insertion or deletion of an item, under a given catalogue heading, then merely requires the revision of the " next-address " or " last address " cross-reference stored in the relevant main-file entries on either side of it. (See Figs. 8a and b). However, in other respects the distributed - catalogue and distributed - index schemes are generally less desirable than the block-index, since the distributed systems require more total storage space and may provide their information in a less accessible form.

A=	*Main-File Addresses*		*No. of Entries*
	First	*Last*	
1	6	13	3
2	1	14	6
3	2	12	4
4	4	15	2

FIG. 7. Index for Distributed Catalogue.

Insertion and Deletion in Catalogues

When a new item is to be entered in a catalogue, next to the existing items under the appropriate heading (or sub-heading), we must find the last item entered. If there are likely to be many items under the given heading, a serial search for the first vacant space may be rather time-consuming. We may therefore examine the space midway through the region of uncertainty. If it is empty we next look midway between that point and the *left*-hand edge but if it is full, we next look midway between the previous sampling point and the *right*-hand edge of the region of uncertainty. (See Fig. 9). Each step in this procedure halves the range of locations in which the last entry might still lie, and so such a binary logarithmic search of N spaces will take only $\log_2 N$ operations.* Alternatively we may avoid the search altogether by maintaining a separate *index* of the last catalogue location occupied (*i.e.* the number of entries in the last block) under each heading, as already suggested in the last section. (See Figs. 5b, 6b and 7).

If the catalogue is to be arranged in order of file serial numbers, similar serial or binary logarithmic searches can find the location within the sequence where a new entry is to be inserted.*

* Sequential catalogues with binary logarithmic searches have been introduced by the author in 1956 and have since proved valuable in a number of practical applications.

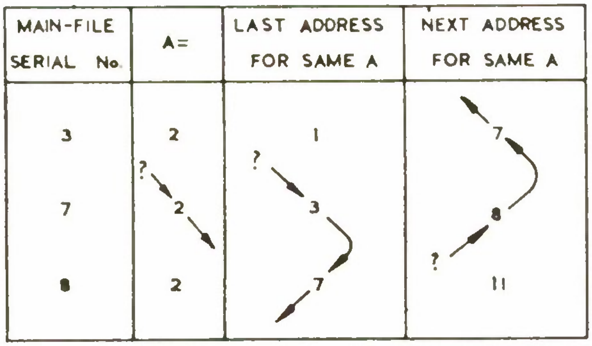


FIG. 8(a). Removal of main file 7 from "chain".

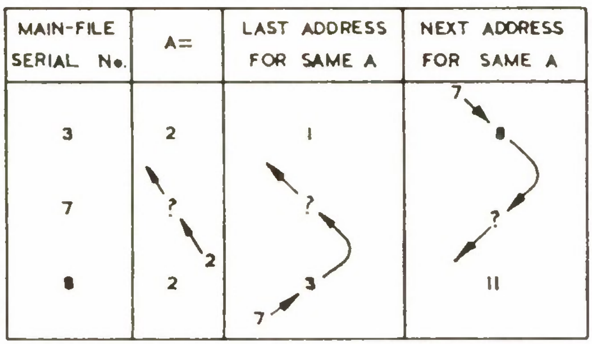


FIG. 8(b). Insertion of main file '7' in "chain".

FIG. 8. Amendments to distributed catalogue sequence.

(See Fig. 10). All further entries must then be *shunted (i.e.* pushed) one space down the catalogue page. The index of the last location occupied is then of little value. This problem of "shunting" is avoided if a distributed catalogue is used as described in the preceding section (and in Fig. 8).

A similar problem may arise when an entry has to be removed from the catalogue:—

In general it is undesirable to leave an unfilled space between catalogue entries. (Certainly such random spacings would not readily fit in with simple and efficient schemes for assigning spaces to new entries). Hence we would probably wish to find the last entry, from an index or by a binary logarithmic search, in order to "fill the hole," left by the deletion, by transcribing the last entry into it. (See Fig. 11). Alternatively—though probably less efficiently—we could provide, in conjunction with each catalogue, a sub-catalogue of the associated vacant spaces, available for filling by new entries. If however we wish to preserve the order of main-file serial numbers, we shall have to close the gap by "shunting" *i.e.* moving up all subsequent entries under the given catalogue heading (or sub-heading). (See Fig. 11).

Up-Dating Catalogues for Changes in Entry Details

Changes to the catalogues are required not only when new members are added to the statistical population covered by the main file or old ones are removed, but also when the relevant recorded parameters, concerning an existing member, change their value, so that this member should be transferred to a new catalogue heading. Three possible strategies for coping with such changes are indicated below:—

(i) We may note which digits, in the relevant parameters, affect the associated catalogue. Whenever the parameter changes, we can then note the old and new values, to identify the catalogue heading(s) previously involved and that (those) requiring a new entry. Appropriate deletion and insertion action

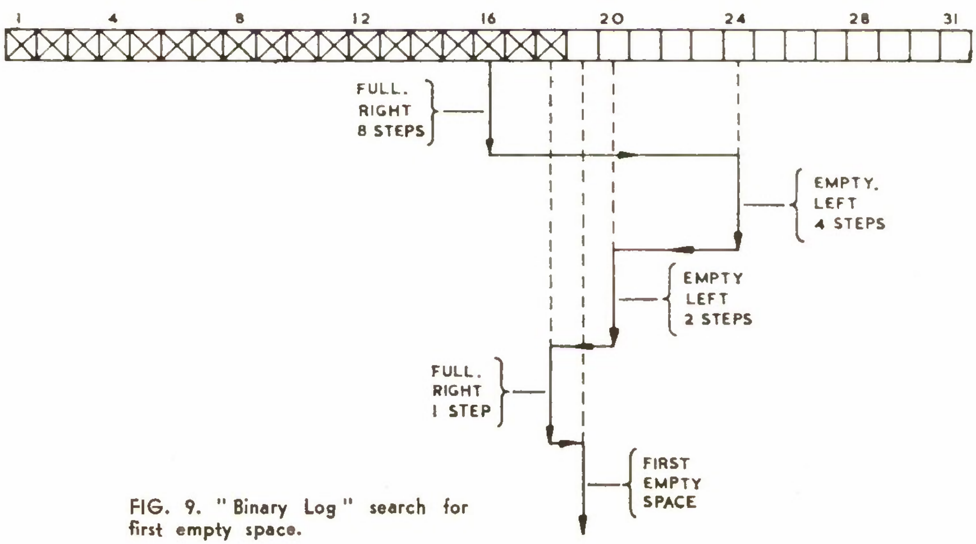


FIG. 9. "Binary Log" search for first empty space.

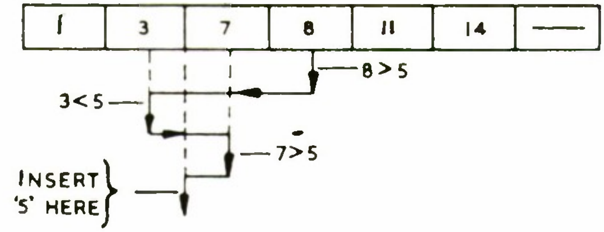


FIG. 10. "Binary Log" search to insert '5' in given sequence.

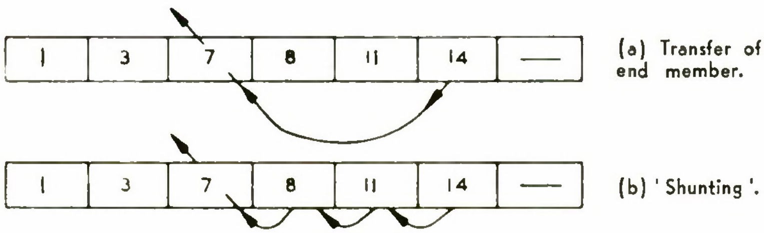


FIG. 11. Gap filling (after removal of '7').

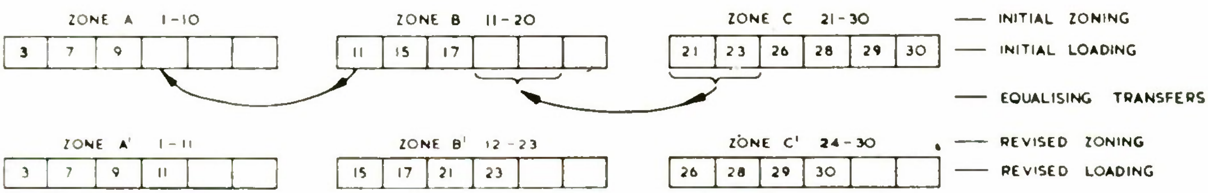


FIG. 12. Zoned ordinal storage with variable limits (not directly related to Fig. 1(a)).

could then be taken immediately. This requires no special provisions in either the main file or the catalogue, but it may require rather frequent catalogue revision.

(ii) We may record the aggregate *change* in the main file, in addition to the old (or new) value of the relevant parameter. At intervals short enough to preclude excessive "staleness" errors, we may then scan through these data and up-date the catalogues accordingly. This reduces the frequency of catalogue revision, but it requires extra main-file storage.

(iii) We may again record in the main file the aggregate change in the relevant parameter, but this time up-date the catalogue only when this change has become large enough to jeopardise the usefulness of the catalogue. This still needs the extra main-file storage (and a few extra programme instructions), but it avoids any needless catalogue revision.

The Value of Address-Sequential Catalogues

The preservation of the order of increasing main-file serial numbers may well be of great value, not only for simpler and quicker operation with a sequential-access main store, but also for any search for members of the population who satisfy conditions involving a logical combination of two or more catalogues. This is a very powerful and valuable technique for content-selective data analysis or retrieval, for moderate or large statistical populations, using normal computer "hardware." It is discussed more fully in Reference (1).

At first sight it might alternatively be desirable to list the population members, falling under a given catalogue heading, in order of increasing value of the parameter which is already presented sequentially, in given coarser magnitude steps, by the catalogue itself. However, if there are sufficient entries under *each* heading, and if the finer steps of magnitude are important in the given context, it is generally preferable to arrange the catalogue itself in finer steps. Hence this technique is useful only if *some* catalogue headings (unknown in advance) might attract a large number of entries whilst others would have too few entries to make efficient use of further sub-divisions. This problem however can be coped with by variable block allocation of catalogue space, as already explained in Section 3. Thus there is generally little to be gained (and more to be lost) by departing from the sequence of main-file addresses.

Cardinal-Value Catalogue Techniques for Ordinal Sorting

Ordinal sorting, in the sequence of increasing values of some parameters, normally entails the recording and use of a *cardinal* (or at least progressive, single-valued, numerical) representation of that parameter, as a basis of comparison. The storage of these cardinal (or similar) values will also normally assist in delimiting the bracket of the ordinal sequence to which a practical operation may be confined, or it may immediately define the approximate (or indeed exact) location, in the sequence, where a new item should be entered.

It may then be desirable to retain the basic catalogue structure based on cardinal values. However, within each catalogue heading, the entries might be arranged in ordinal sequence. Where this is precluded by other requirements (such as serial access to the main file), entries under each catalogue heading might be recorded twice, once in the sequence of main-file addresses and once in that of the relevant parameter value.

As indicated earlier, any amendments to such an ordered sequence require a sequential or logarithmic search and the shunting of the catalogue entries to one side of the relevant location, to make (or close) a gap, as requisite. This shunting operation can be avoided if the sequence is stored in the form of a distributed catalogue, as discussed previously, where each main-file entry includes the main-file address of the members immediately above and below it in the given sequence.

If it is essential to store a large number of rapidly changing entries in an ordinal sequence, the shunting operations to create or close up gaps may become burdensome. It may then be worthwhile to divide the sequence into several zones of (not necessarily equal) cardinal width, all containing roughly equal numbers of entries, and so reducing the shunting load pro rata. However, if the storage space available for one of these zones fills up (or if an excessive disparity develops, in the occupancies of the zones), a group of consecutive entries, at one or other end of a zone, may have to be jointly shunted into the appropriate adjacent zone, the zonal limits being adjusted accordingly. (See Figs. 12a and b). An index defining the zonal limits would then constitute a higher-order ordinal sequence in its own right and, if need be, the same principle could be repeated at yet a higher level.

Conclusions

It has been established that suitable catalogues constitute a powerful tool, for the selection of appropriate members of a statistical population on the basis of numerical criteria. However, the optimum design and use of such catalogues must clearly take into account the broad statistical characteristics of the population itself and of the data concerning that population likely to require analysis. Guide-lines for design of efficient catalogue systems have accordingly been discussed.

Reference

(1) "The Organisation of Computer-Type Stores for the Content-Associative Retrieval of Data-Processing Information". R. Benjamin A.S.W.E. Memo. M 25048/62/XR (20th March, 1962). *J.R.N.S.S.*, **22**, 4 (July 1967), 216-227.

APPENDIX

Illustrative Applications in Air Traffic Control

(a) *Air Plot Compilation*

The functions and facilities discussed in this paper are of importance in a very high proportion of on-line data processing systems. A few hypothetical examples from the limited field of air-traffic surveillance and control may illustrate the type of question which is efficiently answered by the use of the techniques here discussed. (The key words, indicating the type of data manipulation involved, are printed in italics):—

Plot compilation might start with track initiation, by *looking for* radar echoes within given minimum and maximum plan-position (and possibly height) co-ordinates and given limits of velocity.

Subsequent track maintenance may involve *looking for* echoes within given tolerances:

(i) along the track (or direction of an air lane),
(ii) across the track,
(iii) in height,
(iv) in Doppler velocity (if measured).

If there are multiple potential echo associations, it may be desirable to *sort* these *in order* of closeness to the predicted position, in one or more of their co-ordinates.

Somewhat similar criteria of position *tolerances* (differing along the track, across the track and in height), velocity tolerances (in two or three dimensions) and *order* of nearness to the expected position may be used to match tracks to flight plans.

All the above might be modified when IFF or other beacon responses can confirm that an echo should be associated with a given track, or that it cannot do so. Although IFF codes have no quantitative significance, they pose the same requirement of *looking for* given numerical values. Interference, *etc*., might also impose *tolerances* on the number of ONES and ZEROS in the code (or the number of digits differing from the code of interest), and this would need the same treatment as other quantitative data.

Plot compilation may also benefit from counts of the *number* of echoes *within a given area* or volume:

(i) to indicate the load on the detection and tracking system (and its liability to error),
(ii) to give a clue to clutter conditions and to guide the use of anti-clutter techniques,
(iii) possibly to give a clue to weather conditions in different parts of the area surveyed.

(b) *Air Traffic Control and Management*

The safe control of a single aircraft may involve a *quantitative search* for others within combined tolerances of position and velocity and possibly a further, *ordinal search* to establish which of these will constitute the greatest collision hazard. These searches might then be repeated for a number of reasonable, hypothetical changes in course, speed or height of the controlled aircraft, in order to determine suitable avoiding manoeuvres.

More generally, it may be desirable to predict the positions of all tracks, for a given instant in the near future, and to *look for all* instances of two or more aircraft within the same "box", defining the collision-hazard area, or within adjacent boxes. This process can then be repeated for several further instants, a little further ahead, thus *compiling a list* of all impending potential "conflictions" requiring further examination and, possibly, action.

Overall situation assessment, policy formation and operational control might benefit from ready access to information such as the following:—

(i) *What number* of aircraft are within a given section of an airlane? (This single-dimensional information might help to indicate the control load).
(ii) Ditto, including the further dimensions of position across the width of the air-lane—and height, where known. (This might assist in assessing the magnitude of the safety problem).

The following further queries can then be raised in connection with either (i) or (ii):—

(iii) *Where* are they, *in order* of position along the lane?
(iv) *What* is the spacing of these aircraft?
(v) *Who* are they and *what* is known about them?
(vi) What is the *spread and distribution* of velocities?
(This may assist in assessing the magnitude of the collision-avoidance problem and of the problem of maintaining a reasonable spacing of arrival times).
(vii) Does their present positional *sequence* conform with the overall flight plan?
(viii) Are the *spacings* of presently forecast arrival times reasonable?
(ix) Does the *sequence* of presently forecast arrival times match the overall schedule?
(x) For which aircraft are the fuel reserves—expressed in minutes of endurance—*below a given margin* of safety? (Information presented *in order* of increasing fuel margin).
(xi) *What significant departures* are expected (in either direction) from the scheduled arrival times? (This may aid in planning and in preparing acceptance and reception facilities).
(xii) *What significant delays* are being experienced or forecast? (This information may help in assessing—and in endeavours to minimise—disruption of time tables and loss of connection).

Clearly, the facility to obtain rapid answers to questions of this general type is of substantial value, particularly when it is coupled with considerable flexibility, and is limited not so much by foresight as to what questions may arise as merely by the basic constraints on the data available in the main file itself.

MONITORING THE DEEP OCEANS

Lt. Cdr. D. P. D. Scott, R.N.

Every drop of the $1{\cdot}37 \times 10^9$ cubic kilometres of water in the world's oceans is constantly on the move, acting under numerous and varied forces, such as the weather, tides, coriolis force, seismic movements of the earth's crust etc., to name but a few; as will be seen, some of these movements are long term predictable whilst others are dependent on short term variabilities or even on completely unforeseen natural causes.

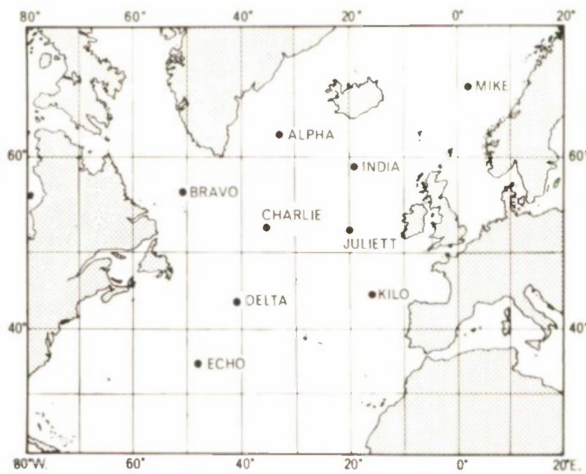
In 1946 when the Weather Ship network was being formed, it was immediately realised that they would offer an ideal and indeed unique opportunity to monitor the movements of water masses and the seasonal and annual cycles of the heating and cooling of the upper layers.

Ocean Weather Ship "Weather Adviser" on Station.

Approaches, made to the International Civil Aviation Organisation (ICAO), by both the International Association of Physical Oceanography (IAPO) and the International Council for the Exploration of the Sea (ICES), met with a positive response and at the London Conference of IACO held in 1947, it was recommended 'that States take advantage of the opportunities provided by these stations for making oceanographical observations and that a progressive oceanographical programme be included in the general scheme of observations.'

National action on the recommendations of the International bodies was however considerably slower. In the Eastern Atlantic, only Norway responded with a programme even approaching that envisaged by the London Conference. The need and opportunity were seen but the money and effort were not forthcoming in a science that had not yet been recognised by governments as of more than marginal value.

In 1959, with the full co-operation of the Director, Meteorological Office, the Admiralty Underwater Weapons Establishment, Portland, planned a routine series of physical observations from the British Ocean Weather Ships. Oceanographic winches were fitted in the four Castle Class frigates, then being converted to replace the original Flower Class corvettes and in February 1961, deep casts were started once a week, to 3,000 metres, using reversing water bottles and thermometers; temperature profiles of the upper layers were also obtained twice daily by Bathythermograph, originally to 135 metres (450 ft.) and subsequently, as instruments became available, to 270 metres (900 ft.).



North Atlantic Ocean Stations (N.A.O.S.)

ALPHA	France, Netherlands, Norway, U.K.
BRAVO, CHARLIE, DELTA, ECHO	U.S.A.
INDIA	U.K., Netherlands.
JULIETT	U.K., France, Netherlands.
KILO	France, Netherlands, U.K.
MIKE	Norway, Netherlands.

Responsibility for these observations has more recently been transferred to the Hydrographer of the Navy and the Ministry of Agriculture, Fisheries and Food, Fisheries Laboratory at Lowestoft, under the guidance of the Natural Environment Research Council, Working Group on Ocean Data Stations.

The observing programme has been developing steadily over the years and, due to the excellent co-operation from the ships and the Ocean Weather

Ship Base at Greenock, the resulting data are now of high quality. In addition to these routine serial water observations, other routine physical and biological work is carried out, both on station and on passage to and from the Clyde, such as Current Observations by Navigational Methods for the Meteorological Office, the laying of Surface Drifters for the Department of Agriculture and Fisheries for Scotland, Surface Water Sampling for the Ministry of Agriculture, Fisheries and Food and the towing of Hardy Plankton Samplers for the Scottish Marine Biological Association.

On occasions the ships are used for 'special projects' by various departments, such as the investigations into Internal Waves made by the Director of Meteorology and Oceanographic Services over the last two years, but special parties are almost always embarked for such work.

As the project has progressed, it has become clear that continuous time series of observations cannot be obtained at internationally shared stations without close co-operation between the participating nations, in order to ensure that similar types and series of observations are made when a ship of one nation takes over from another.

The compatibility of observations has been discussed by the Inter-governmental Oceanographic Commission (IOC) who suggested that ICES might be willing to co-ordinate the shared North Atlantic Ocean Stations (NAOS)—Alpha, India, Juliett, Kilo and Mike which all fall within their area. This proposal was accepted by ICES and a meeting was recently held at their headquarters at Charlottenlund, Denmark which was attended by representatives from the Netherlands, Norway, United Kingdom and ICES and observers from the U.S.A.

Little disagreement was shown on the value of the long-time series of observations in the deep ocean and the need to obtain them whilst the opportunity still exists; it is therefore to be hoped that, if the momentum can be kept up, difficulties will be overcome and all countries in the scheme will see their way to closer co-ordination and standardisation of their observing patterns and techniques.

NATO OPERATIONAL RESEARCH CONFERENCE ON RECENT DEVELOPMENTS IN LANCHESTER THEORY

Reported by P. R. Wallis, B.Sc., R.N.S.S.
Admiralty Underwater Weapons Establishment

In 1916 F. W. Lanchester, the automobile and aeronautical engineer, published his book on "Aircraft in Warfare: The Dawn of the Fourth Arm" (reference 1). Ever since, the use of differential equations to study the attrition of the forces of two sides engaged in military combat has been known as Lanchester's Theory of Combat. During the first week of July 1967, NATO workers in the field of operational research gathered together in the Federal Republic of Germany's Army Engineering School at Munich to discuss recent developments.

The discussions covered deterministic models, stochastic models, validation and applications. They helped very many to a clearer appreciation of the potential, limitations and appropriateness of the models; I shall try to pass this on.

Deterministic Models

A simple version of one of Lanchester's original form of equations is as follows:

$$\left.\begin{aligned}\frac{dm}{dt} &= -\beta m,\\ \frac{dn}{dt} &= -\alpha n.\end{aligned}\right\} \quad \ldots\ldots (1)$$

In this m and n are the numbers of troops, aircraft or other units engaged on each side and α and β are constants corresponding to the combat effectiveness of the two sides. This form of equation is associated with a situation of aimed fire, in which, for example, the rate of fire by red and the number of red units remaining will determine the rate of loss by blue. Dividing the two equations to eliminate time and integrating gives

$$m_0^2 - m^2 = \left(\frac{\alpha}{\beta}\right)\left(n_0^2 - n^2\right),$$

where m_0 and n_0 are the initial forces. This is known as Lanchester's Square Law. Another form of equation is appropriate when area fire is used or the sides have difficulty in locating targets rather than firing fast. In this case the right hand side of the equations will depend also on the number of targets and perhaps become mn; this gives Lanchester's Linear Law:

$$m_0 - m = \left(\frac{\alpha}{\beta}\right)\left(n_0 - n\right).$$

Further forms of the equations were discussed in several of the papers. One development following

earlier work by S. J. Deitchman was discussed in papers by N. Kurdyla, J. P. Mayberry and M. B. Schaffer. This involved asymetric forms such as:

$$\left.\begin{aligned} \frac{dm}{dt} &= -\propto mn - \delta\,(t).m\ , \\ \frac{dn}{dt} &= -\beta m\ , \end{aligned}\right\} \quad \ldots\ldots (2)$$

which can be used to model ambush or siege situations; in this the side m is the ambusher or the garrison and is dug in and difficult to locate; the extra term δ represents artillery or aerial fire-power that could be called up after a delay.

Another development reported in a paper by D. O. Etter was the addition of spatial dimensions to the combat, with specifications of weapon kill range and, most interestingly, with force mobility over the plane. He used as one example a column attacking a defensive line, though he pointed out that the analysis showed this to be far from an optimum attack. Though his analysis did not proceed beyond optimisation by one side against a fixed policy of the other, it was clear that the model would provide payoff values for an essentially game theoretic study. Some mathematically simpler but more limited approach to the spatial problem was given by J. C. Holladay using subdivision of the forces into geographic regions.

Validation

Dr. J. H. Engel of the U.S.A's Centre for Naval Analyses was Conference Director and he made it very clear than an operational research scientist must seek validation of his mathematical models. In reference 2 he had used the casualty data from the Iwo Jima battle of World War II and demonstrated that the variation of casualties with time gave a remarkably good fit to that predicted by equation one. He had however determined an $\propto/\beta$ combat effectiveness ratio of 5 : 1; his explanation in terms of a siege situation suggested however that equation two might well be more appropriate; he offered to test this case as well.

R. L. Helmbold in his paper complained that historical battles were rarely well enough recorded to provide more than two points, the initial and final ones; with two sides and two unknown parameters the proof or disproof of any particular law was not possible from any one battle. However if one was permitted to assume that the law parameters remained constant over many battles some discrimination might be obtained. He reported such tests applied to some 100 historical battles and found the scatter for the linear and another law too large to support them. Nor could he reach an encouraging result with the square law because, although the scatter was smaller, a marked unexpected trend in combat effectiveness ratio (the deduced $\propto/\beta$) with force ratio m_0/n_0 was present. D. G. Smith suggested in discussion that the result might be explained if Lanchester's square law applied to a battle between groups, the ratio of whose sizes was the same as the initial force ratio.

L. J. Byrne felt that the evidence from modern battles supported a modified form of the square law. M. J. Bresson was also keen on the use of history and reported on studies of the Soviet advances against the German Eastern Front in 1944. His analysis bore more on the need to include logistic constraints than on the combat laws themselves.

Stochastic Models

The Lanchester laws are deterministic, predicting annihilation of one side at a precise time; this does not accord with reality. The quantities m and n are continuous quantities, though a fractional soldier is not a useful contribution to an army. Lanchester himself and all users interpret these variables therefore as expected or average values. No information is obtained however about the distribution and the expected value is known to be invalid when the battle is fought near annihilation or the number of participants is small. The stochastic models (see for example reference 3) offer an alternative approach.

I think the stochastic model is appropriate in the following three circumstances:

(a) When the number of participating units is small and the Lanchester expected values are in considerable error. This is particularly likely when the battle is bloody.

(b) When the payoff to the military planner (or analyst) is dependent on the probability distribution of survivors and cannot be expressed in terms of the expected value, however correct. This may arise if the value of the survivors for later operations is non-linearly dependent on their numbers. Alternatively the commanding general may aim to exceed a certain minimum probability of victory.

(c) When losses in the engagement are highly correlated.

Two papers, one by P. R. Wallis and the other by W. Hardeck and H. Hilden, presented the formulation for the probabilities of any combination of force numbers (integral quantities) at any time in terms of a set of difference equation of form:

$$\frac{dP_{m,n}}{dt} + \left(\propto_{m,n}+\beta_{m,n}\right) P_{m,n} = \propto_{m+1,n}P_{m+1,n} + \beta_{m,\,n+1}\ P_{m,\,n+1}.$$

In this $\propto_{m, n}$, for example is the probability density function for the loss of one unit of side m when there are extant m of that side and n of the other. Solution of these equations can be obtained by systematic integration, as used in a paper by R. Willstadter and C. R. McClung, or, as presented in the paper by P. R. Wallis, using Laplace transformers. The latter paper also extended the analysis to combat involving several different types of unit and simultaneous or multiple losses. The latter are necessitated by the structure of certain forms of battle, e.g. ASW, due to the correlations present.

The papers demonstrated the convergence to the Lanchester expected values when the numbers of units were increased indefinitely and the probability distributions and errors in the expected values when force numbers were small.

A major advantage of the stochastic method was seen in the unrestricted choice of the constants $\propto_{m, n}$ *etc.* This enables detailed study of tactics. In the Lanchester equations an explicit dependence on m and n must be adopted. The disadvantage in the stochastic method lies in the amount of computation required, which increases rapidly with the number of units involved. Modern computers have extended the size of problem that can be handled, however, and there is little difficulty in application to typical problems involving warship or aircraft combats.

Alternative forms of the stochastic model were discussed in papers by D. G. Smith and K. C. Bowen in which time is replaced as a variable by a count of the total number of events. There may be some computational convenience in doing this but at the cost of having to use additional estimates for battle duration. The former paper made some comparisons with a computer simulation and met some " overkill " difficulty which may be related to the use of event rather than real time. Bowen is able, for the case corresponding to Lanchester's square law, to determine the lower moments approximately when the probabilities of annihilation are negligible. It is interesting to note in passing that early in the battle binomial distributions are obtained when working in event terms, whereas the early form is of course Poisson when working in terms of time. Bowen meets difficulty in obtaining closed forms for the moments when the battle proceeds to near annihilation or has the more complex structure arising in ASW.

B. W. Connolly's paper examines an ASW problem using the time dependent stochastic equations and the Laplace transform solution. He avoids the attrition problem and the resulting unclosed form of solution, however, by postulating the immediate replacement of any casualties.

Applications

In addition to the applications included in the above papers, several others by J. P. Mayberry, D. R. Howes, E. P. Kerlin, C. N. Beard and J. Krol make use of modified forms of the Lanchester differential equations in computer simulations and games. Beard's paper discussing a set of army war games, not using a computer, raised some interesting statistical comments.

The Chairman was not alone in expressing the view that the analyst needed to obtain at least some measure of experimental verification of the models or simulations before confidence could be placed in the conclusions.

Members of A.U.W.E., D.O.A.E., R.A.R.D.E. and R.C.M.S. attended and found it an interesting and profitable conference.

References

(1) Lanchester, F. W., "Aircraft in Warfare: The Dawn of the Fourth Arm," Constable and Company, London, 1916.

(2) Engel, J. H., "A verification of Lanchester's Law," *Operations Research*, **2,** 2 (May 1954), 163-171.

(3) Morse, P. M. and Kimball, G. E. " Methods of Operations Research," Wiley, New York, 1951, pp. 61-80.

(4) Conference papers will be published in due course but can also be obtained individually from the Library at A.U.W.E. and D.O.A.E.

RETIREMENTS

W. W. JACKSON, M.Sc., Ph.D., R.N.S.S.

Henry VIII's Wine Cellar under the Ministry of Defence Building in Whitehall was the scene of a ceremony on 29th June when Dr. William Welsby Jackson retired after 31 years service to the Navy. If any ghosts of Henry VIII's retainers were around at the time we didn't see them—not at the early part of the evening anyway, but were they there they could not have been more pleased with the ceremony in such a unique setting than were the guests who gathered to offer their best wishes to Dr. and Mrs. Jackson.

Gaining his B.Sc., with first class honours in physics, at Manchester University in 1928, Dr. Jackson obtained his M.Sc. with a thesis on "X-Rays and Crystal Structure" the following year and was subsequently elected Darbishire Research Fellow of Manchester University. In 1930 he was appointed Carnegie Teaching Fellow and University Lecturer at Aberdeen. His thesis on "Transition Probabilities within the Hydrogen Atom" gained him his Ph.D. in 1933 and later he undertook post-graduate research in the Cavendish and Solar Physics Observatory at Cambridge.

In 1936 Dr. Jackson joined H.M.S. *Osprey* at Portland which led to him becoming Head of Research at U.D.E. in 1946. The year 1949 saw him as Deputy, later Acting Chief Scientist, and he was transferred to Headquarters as Assistant Director of Physical Research in 1951.

His promotion to D.C.S.O. came in 1955 and in 1964 he was appointed Deputy Director of Physical Research, the post he held until his retirement.

Dr. Jackson has made many important contributions in the underwater field; the earlier ones included Lobe Comparison Systems for Torpedo Homing, Bubble Screens and the Shadowgraph. More recently at Headquarters he has taken a particular interest in international collaboration. He became a well known and much appreciated member of TTCP Sub-Group G and on the European side controlled the research contract on acoustics with Göttingen University. Equally important in the international sphere has been the wealth of informal contact arising from his high personal standing in the ASW world. His more local interests in D.N.P.R. have included Mine Countermeasures, Radiological Defence, Submarine Escape and a contract on Cavitation with Cambridge University.

Fortunately the R.N.S.S. is not to lose Dr. Jackson just yet and we wish him every success and happiness in his new duties at the Admiralty Compass Observatory.

No friend of Dr. Jackson would consider this appreciation complete without a mention of the Rolls Royce; perhaps the next Concours D'Elegance will feature a gyrocompass amongst its other exotic instruments!

J. G. BRACK, R.N.S.S.

On Friday, 28th April, 1967, many colleagues and friends gathered at A.S.W.E. to wish "bon voyage" and good fortune to Mr. John George Brack, Senior Draughtsman who, at the age of 55 voluntarily retired from R.N.S.S. to join the Naval Central Drawing Office at Canadian Vickers Ltd., Montreal, Canada.

He is shown on the left being presented with a silver tray by Mr. A. Lambert, Head of Drawing Office.

E. A. WILLOUGHBY, B.E.M., R.N.S.S.

Mr. E. A. Willoughby (Nick) of the Installation Division at A.S.W.E. retired on 31st March, 1967, after 50 years service to the Crown.

Born in 1900 he joined the Royal Navy at the age of 15 and went into the Signal Branch. He reached the rank of Commissioned Telegraphist and in 1945 he retired from the Royal Navy to take up a civilian post in the Installation Division of A.S.W.E. remaining in this division until his retirement. In 1960 he was awarded the B.E.M. for his services.

Mr. Willoughby's Service experience was invaluable, and many projects benefited from this experience in the installation of their equipment. His advice was often 'laced' with a salty tale, told in a typically Naval style.

At the farewell ceremony, Nick, shown in the photograph, was presented by Mr. J. Snowdon with a silver tray and vase, a clock, and a cheque with which to buy an electric drill.

E. J. WALSH, R.N.S.S.

Mr. E. J. Walsh, Senior Experimental Officer, and Standards Officer of the Admiralty Surface Weapons Establishment retired on the 31st March, 1967, after 45 years in the Service. He commenced his career in 1922 as an Engine Fitter Apprentice at H.M. Dockyard, Rosyth and moved South after his apprenticeship joining the Signal School Drawing Office in 1929. He was evacuated with the drawing office to Haslemere early in the last war, and was transferred to the Technical Grade as an Assistant I in 1942, and ultimately promoted to Senior Experimental Officer in 1951.

In his capacity as Standards Officer he represented the Establishment and Navy Department on many of the Standardisation Committees.

On behalf of his many colleagues, the Chief Scientist, A.S.W.E., Mr. D. Steward-Watson presented Mr. Walsh with a cheque with which to purchase a lawn mower.

W. C. CHAPPLE, R.N.S.S.

Mr. Claude Chapple, Senior Scientific Assistant retired on 24th April, 1967. Mr. Chapple had a varied career. He joined H.M. Dockyard Devonport as an apprentice in 1918 and commenced duty as a Draughtsman in the Signal School in 1928. In 1932 he joined H.M. Customs and Excise as a Departmental Clerical Officer, serving at Fishguard, South Wales. At the beginning of the last war he was recalled to the Admiralty Signal Establishment, again serving in the Drawing Office until 1946 when he rejoined the Customs and Excise in London. He was attracted back to the R.N.S.S. and in 1948 he rejoined the then A.S.R.E. as an S.S.A. in the Engineering Services Division.

On behalf of his many colleagues Mr. Snowdon presented Mr. Chapple with an electric razor, kitchen clock, and garden seat.

OBITUARY

R. W. ROBINSON, A.I.M., R.N.S.S.

The death occurred in June 1967 of Ronald William Robinson at the early age of 51 and so perhaps the last serving personal link between the present Central Dockyard Laboratory organisation and the original Engineering Foundry Laboratories has gone.

His scientific career commenced when he joined the staff of the Foundry Laboratory, H.M. Dockyard, Chatham in 1936, where he was principally concerned with the production of aluminium alloys and high duty cast irons.

In 1947 he went to Malta as Officer-in-Charge of the Metallurgical Laboratory, returning in 1950 to the central Metallurgical Laboratory, Emsworth. He was appointed Officer-in-Charge, Metallurgical Laboratory, H.M. Dockyard, Devonport, in 1951 and promoted to Senior Experimental Officer. His age at the time of his promotion, 35, made him one of the youngest Officers ever to have held this rank.

In 1963 he was instrumental in re-organising the laboratory to give a broader based scientific service to all Dockyard Departments and local fleet units. He was a dedicated advocate of close co-operation between scientist and engineer at all levels and firmly believed that the pure scientist should occasionally operate in the applied field, to the advantage of all.

He was the author of a paper entitled "Scientific Service to Management" published in the Journal in May 1965 in which he described in detail the nature of the service he considered a modern Dockyard laboratory should offer. It is no small tribute to him that many of the concepts he advocated so vigorously are now a fundamental part of the service to which he devoted his working life.

The same buoyant energy he displayed in his work was also reflected in his personal life and his many activities included golf, gardening and caravanning. He was an enthusiastic "Do It Yourself" man and made use of the talent to further another great interest, the collection of antique furniture. Thus he acquired basically sound, albeit somewhat worn, pieces at modest cost, and then, with the able assistance of his wife, restored the same in a most effective manner.

His exacting sense of duty and strong, colourful, personality will be sadly missed on the Dockyard scene, particularly by his many friends and colleagues.

He leaves a widow, son and daughter.

Notes and News

Admiralty Compass Observatory

Miss Joan Lestor, M.P. for Eton and Slough, visited A.C.O. during February and made a tour of the Establishment conducted by members of the directing staff.

Mr. E. J. Hall, Associate Director, Mr. R. Ragan and Mr. A. Deprete members of the gyro group of the Instrumentation Laboratory, Massachusetts Institute of Technology, visited the Observatory during March.

Mr. E. J. Burton, Mr. P. Smith and Mr. A. G. Patterson attended the International Gas Bearing Symposium held at Southampton University during April. Mr. Patterson took the chair in Session III and led the discussion in Session IV.

A deputation of members of the U.S. Office of Naval Research Gas Bearing Co-ordination Committee, comprising Mr. S. W. Doroff, Dr. C. Par, Dr. L. Licht, Mr. O. Decker and Dr. J. Vohr paid a liaison visit to A.C.O. during May. Subsequently under A.C.O. sponsorship they visited a number of British R. & D. establishments also working on gas bearings.

Dr. R. H. Purcell, C.R.N.S.S., visited the Observatory during May.

Mr. H. J. Elwertowski, Chief Scientist and Deputy Director Research and Development, headed the British Delegation to the NATO Long Term Scientific Study Conference on Navigation, held in Oslo during June.

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Admiralty Materials Laboratory

Mr. J. S. Beard left the Rubber and Plastics Division to take up his new appointment as Head of the Chemical Engineering Division on 1st June, 1967.

Mr. D. L. Griffiths, who has been serving as a member of the Scientific Mission in the British Embassy at Washington, returned to A.M.L. as Deputy Head of the Rubber and Plastics Division on 5th June, 1967.

Mr. D. Birchon presented a paper entitled "Selection and Correlation of Non-Destructive Testing Techniques—an Introduction to the LEO System" at a T.T.C.P. Symposium held at Orlando, Florida, in May and followed this by visits to the U.S. Naval Applied Sciences Laboratory and the Brooklyn Polytechnic.

Dr. D. J. Godfrey visited the U.S. and Canada during May and June in connection with T.T.C.P. Sub-Group P Panel 2 meetings.

Mr. J. J. Elphick visited Paris on 9th May as U.K. delegate at a meeting held to consider the future organisation of the International Co-operative Research Group on the Biological Deterioration of Materials, originally established by O.E.C.D.

Mr. D. W. Butcher presented a paper entitled "How to Reduce Condenser Sizes by the Efficient Condensation of Steam" at the conference on "Industrial Physics—the

Contribution of Government Laboratories" organised by the Institute of Physics and The Physical Society in collaboration with the Ministry of Technology at Harrogate on 7th-9th June, 1967.

Mr. R. L. Brown presented a paper entitled "The Flame Sprayed Deposition of Silicon Powder for the Production of Silcon Nitride Ceramics" at the Second Divisional Conference of the Institute of Welding (Metal Spraying Division) in London, 17th-19th May, 1967.

The following papers have been published: "Engineering Materials at Sea" by L. Kenworthy, *Navy*, **72** (1967), 141, and "Delayed Fluorescence and Some Properties of the Chlorophyll Triplets" by C. A. Parker and Thelma A. Joyce, *Photochem. Photobiol.*, **6** (1967), 395.

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Admiralty Surface Weapons Establishment

Mr. Herbert Mills Bristow, Principal Scientific Officer, retired from the R.N.S.S. on August 4th, after 31 years service with the Establishment.

Captain H. R. Wykeham-Martin, A.S.W.E.'s Deputy Captain, left the Establishment at the end of June to take his new post at H.M.S. *Cochrane* as Chief Staff Officer (Technical) to the Flag Officer, Scotland and Northern Ireland. He has been relieved by Captain P. G. Wigney, R.N.

Recent visitors to the Establishment have included:— Air Vice-Marshal Foden, Assistant Chief of Staff (Signals) and Vice-Admiral Sir Horace Law, the Controller of the Navy.

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Admiralty Underwater Weapons Establishment

A particularly pleasant gesture was made recently by the Naval Ordnance Laboratory at Whiteoak, Maryland, U.S.A. when an attractive crest of the laboratory was sent to A.U.W.E. to mark the close relationship existing between the two establishments. A.U.W.E's connection with N.O.L. goes back a number of years and a considerable number of our readers have visited this laboratory in its delightful setting.

A presentation was made recently to a well-known figure at A.U.W.E., who although not a member of the R.N.S.S. must be known to so many who have worked at A.U.W.E. and the old U.D.E. The presentation to Mr. Bertie Cloke was to mark his retirement after fifty-two years' Crown service, during which time he had served in all three of the Armed Services and the Civil Service.

In June 1914 he joined the Army and rose to the rank of sergeant in the Northumberland Fusiliers. After three years in the trenches he volunteered and was accepted for training as a pilot in the then Royal Flying Corps and commissioned as a 2nd Lieutenant. In 1919 he was demobilised and almost immediately joined the Royal Navy as a Writer and rose to Chief Petty Officer before retiring on pension in 1937, his previous armed forces service time counting towards his pension.

Almost immediately after retirement from the Royal Navy, Bertie Cloke joined the Civil Service as a Pensioner Clerk and very quickly his capabilities led to promotion first to Clerical Officer in 1953 to Higher Clerical officer and two years later to Executive Officer. During these years he served almost continually at U.D.E. and H.M.S. Osprey except for a short period at a Naval Air Station. In 1959 with the setting up of A.U.W.E. he was responsible for the Registry Organisation and the filing system which is in use today. His meticulous attention to detail and complete willingness to help his colleagues contributed greatly to the smooth running of the Establishment and his pungent wit and at times salty and original vocabulary made him a character to remember.

His health over the past year or so has now forced Bertie Cloke to retire—unwillingly—at the age of 70 years and 3 months and all at A.U.W.E. wish him a long and restful retirement.

A visit was paid recently to A.U.W.E. by Mr. Roy Mason, Minister of Defence (Equipment) where he was briefed on the projects under development and the research programme by the Chief Scientist Dr. R. Benjamin. Mr. Mason was later conducted around the laboratories where he talked with Project Leaders and their teams and tea was taken with the chairman and secretary of the Whitley Committee. The photograph shows Mr. Mason being greeted on his arrival by Dr. Benjamin.

In May, the Controller of the Navy, Vice Admiral Sir Horace Law, K.C.B., O.B.E., D.S.C., visited A.U.W.E. together with Mr. B. W. Lythall, Chief Scientist (R.N.) and Rear Admiral H. R. B. Janvrin, Deputy Chief of Naval Staff. During the forenoon, heads of Divisions gave short briefs to the Controller on the work of their divisions. A buffet lunch was held in the Principal Officers' Mess A.U.W.E. (S) which gave the visitors time and opportunity to meet and talk with mess members. The afternoon was spent in discussion with the management and the visitors left by helicopter for Northolt.

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At the NATO Conference on Operational Research held at Munich in early July, where recent developments in Lanchester Theory of Combat were discussed, Mr. P. R. Wallis, head of the Assessment Division presented a paper, "A Model for Force Attrition". A brief report on the conference is reproduced elsewhere in this edition.

An unexpected overseas trip was enjoyed by Mr. Philip Smith, a Sandwich Course student whose subject is mathematics at Brunel University and who accompanied Mr. Wallis to Munich. Mr. Smith is doing his first period of "industrial" training at AUWE and is working on the application of computers to the analysis of battle situations in the ASW field.

A two-day visit was paid recently to AUWE by the Deputy Controller Guided Weapons at the Ministry of Technology, Dr. B. G. Dickins, CBE. He was accompanied by four members of his staff and on the first day the visitors were given a tour of the establishment and a briefing on some of the projects under development. On the second day, the Director General Weapons (Naval) Rear Admiral A. M. Lewis, CB, together with other Directors of the Weapons Department met to discuss projects with which both Ministries were concerned.

On Friday, 14th July, the Establishment held its annual official Cocktail Party to which over 50 local dignatories and personalities were able to accept invitations. The main entrance hall and upper landing at AUWE (South) were florally decorated for the occasion and a total of 270 guests of the Principal Officers' Messes at AUWE(N) and AUWE(S) and their hosts were in attendance. Judged by the noise output and rather late departure by some of the guests it has been assumed that the party was a great success.

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Services Electronics Research Establishment

Mr. G. P. Wright and Mr. P. Gurnell paid a three day visit to Paris in June in connection with the Anglo-French Working Group on Valves and Semiconductors.

Mr. H. Foster visited Washington on 6th June to attend a conference on "Laser Engineering and Applications", organised by the Institute of Electrical and Electronics Engineers, and the Optical Society of America; this was the first conference to be held on this subject. It is hoped to hold a similar conference every two years alternating with the established Quantum Electronics Conference.

More than 90 papers were presented at the conference showing slow but steady progress in the unclassified areas of laser applications. A commercial exhibition of lasers and components was held at the same time as the conference. Exhibitors literature and a digest of the technical papers are held by Mr. J. Paskin, G.W.(G&C)5, Mintech, Castlewood House. Selected papers will be published in full in Journals of I.E.E.E.

Mr. E. J. Sherwell visited Santa Barbara, California, U.S.A. to attend the Solid State Devices Research Conference, 19-21, June 1967. His report of the Conference is to be published in our November issue.

On July 17th S.E.R.L. was host to a group of 25 visitors from the Cambridge Philosophical Society. The Society is the major scientific society in Cambridge, and all branches of natural science are included within its scope. Among the visitors were the President, Sir Rudolph Peters, F.R.S., who is a distinguished biochemist, and some eminent mathematicians and physicists. Several aspects of the work at S.E.R.L. were demonstrated, including neutron tubes, ion implantation, semiconductor material preparation, crystal lamps, high-power gas lasers, the ring laser and holograms. Despite the oppressive heat of the day, the exhibitions aroused a lively interest. During the tea-party which ended the visit, Sir Rudolph thanked S.E.R.L. for its efforts in arranging the demonstrations, and emphasized the value of the cross-fertilization of ideas which occurs when a non-specialist society of scientists has the opportunity of visiting such an establishment as S.E.R.L.

Three Members of Parliament, Mr. F. Hooley, Mr. D. Watkins and Mr. J. Allason, accompanied by Dr. R. G. H. Watson, Head of R.D.F.(N), visited S.E.R.L. on 18th July and toured the Laboratory.

About 20 officers of the No. 10 Advanced Weapons Course, R.A.F. College, Cranwell, visited S.E.R.L. on the 27th July. Their itinerary included demonstrations of the research on semiconductors and gas lasers being carried out at the Establishment.

Mr. R. W. Sutton, Superintendent, S.E.R.L. (centre) with (from left to right), Mr. F. Hooley, M.P., Mr. D. Watkins, M.P., Mr. J. Allason, M.P., Dr. R. G. H. Watson, Head of R.D.F.(N), and standing, Mr. R. Redstone, Mr. G. P. Wright, Mr. P. Gurnell, Mr. P. D. Lomer and Dr. H. A. H. Boot.

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Services Valve Test Establishment

Mr. B. W. Lythall, Chief Scientist, Royal Navy, visited the Establishment on 23rd June, 1967; he visited the laboratories, meeting members of the staff and discussed the work they were carrying out.

Mr. H. Lewis visited Canada during the period June 5th to 17th, 1967, to attend a meeting of NATO Special Working Group 13 (Semiconductor Devices) of which he is Chairman. The Group also visited Government and Industrial laboratories to examine developments in the solid state field, especially hybrid integrated circuits.

Book Reviews

Theory of Structures. By G. M. Mills. Pp xii and 449. Macmillan & Co. Ltd., London and Toronto; St. Martin's Press Inc., New York. 1964. Price 37s. 6d.

This book is obviously primarily intended for students rather than for practising or research engineers. It follows the somewhat pedestrian modern trend of teaching by example, with perhaps too scant a treament of underlying principles in most places. However, the analysis chosen for most problems is simple and clear to follow, and the book is very suitable for students taking a degree or diploma of technology in Civil Engineering, or studying for the Theory of Structures examinations of the Institutions of Civil and Structural Engineers. The abundant examples are mainly from examination papers of London University or I.Struct.E. Many are fully worked out and students should find little difficulty in following them. The treatment of wind forces, steelwork joints and torsion is somewhat scant for some of their syllabuses and no mention is made of temperature stresses (e.g. in arches) or the effects of foundation movements. Greater use of graphs and references would have helped the student, but these are all fairly minor criticisms.

The reviewer feels that a modern text should include some reference, however brief, to such topics as unstable collapse of frameworks, shakedown, matrix formulation of structural theory for digital computer solution, the effect of cladding and plating in framed structures, statistical treatment of service loads, and a brief discussion of choice of materials and criteria of acceptability to be used in design, and hopes they may be included in later editions. The author in his preface claims to give a clear understanding of the basic principles underlying structural Design. This is a common assertion in many modern engineering texts, no doubt fostered by sales pressures, but it is very largely not true as any design engineer readily detects by the absence of such words as codes, criterion, materials, safety, etc. from the index or contents. Analysis, which forms the vast majority of such texts, is unquesionably a necessary part of design, but it is but a tool in the whole process, and in many cases a rather imperfect tool at that. Having said this the reviewer hastily defends Mr. Mills book providing he, the publishers and potential buyers are under no illusion that it covers structural design.

The book falls naturally into three sections, statically determinate structures (Chapters 1-7), stress and deformation (Chapters 8-11) and statically indeterminate structures (Chapters 12-20). The statics of forces in plane and space frames emphasises quite properly the method of tension coefficients. Statically determinate beams and cranked beams are very adequately covered, as are the chapters dealing with suspension cables, three-hinged frames and arches, moving loads and influence lines.

The middle section deals with stress, strain and energy relationships for homogenious and composite beams, and then considers the various graphical and analytical methods of predicting deflections in beams and frames including a short paragraph and example on impact loading. It is in this section of the book that the student is really introduced to the important but oft forgotten notion that there are very often alternative methods of analysis available, each with its special merits, and this approach is developed more extensively in the later chapters of the book where the author clearly draws effectively from his teaching experience.

In Chapter 12 the author discusses in a refreshing and sensible way the general principles for statically indeterminate structures. Redundancy is admirably covered, as is the unit displacement and unit force methods of analysis with a helpful discussion of their relative merits. These ideas are extended in later chapters, and it would perhaps be logical to introduce the reader to matrix formulations (for computer solution) at the end of Chapter 14 which covers slope-deflection (it would be helpful to have displacements expressed in terms of forces as well as the more usual converse) and moment distribution methods as applied to continuous beams. Extension to frames, arches and rings follows, and the treatment, including the effect of "sway," is better than that found in most texts and should present no difficulties to the student.

Chapter 18 "Struts" is the only chapter dealing with instability in the whole book, which perhaps reflects an inadequacy in current examination syllabuses. The effect of axial load on beam stiffness is considered (graphs would be particularly helpful here). The last two chapters include the reciprocal theorem, model analysis, influence lines for redundant frames, plastic theory for steel and reinforced concrete beams and frames and yield-lines theory for collapse of plates and slabs. All are treated admirably for instruction purposes.

Good clear drawings abound, many in the margins exactly adjacent to the relevant text. This demands wide margins (less than 60 per cent of the page width is used for the text) which may be useful for notes, but appreciably increases the book thickness and weight. The text is clear and remarkably free of typographical errors (there is a dimensional error in the first equation of Fig. 14.6). As there is no dynamics in the book the author has treated units consistently using tons and inches (why not the British Standard "tonf" for force ?). Each chapter is concluded with a welcome summary, references and problems, and cross referencing to earlier parts of the text is well executed. There are not many British books which deal specifically with Theory of Structures syllabuses, but this one can be confidently recommended. Some knowledge of calculus and elementary applied mechanics is assumed, but the treatment throughout is lucidly simple with a refreshing discussion of the various methods of analysis available which should prove valuable to most students.

D. Faulkner

Computers and Thought. By E. A. Feigenbaum and J. Feldman. Pp. xiv + 535. London; New York. McGraw-Hill Publishing Co. Ltd. 1963. Price 64s.

This is a very fine book. It deals with a subject which is at present in its infancy but which, with time, will probably become extremely important.

New subjects invariably introduce difficulties in semantics and this is no exception. But the authors pay much attention to defining the new words which are being added to the language of computing.

The book is divided broadly into two parts: Artificial Intelligence and Simulation of Cognitive Processes. It serves as an introduction to new students and as a convenient reference volume for the specialist. The bibliography is very systematic and extensive.

Basically, the problem being considered is how to make the large computing machines now at our disposal develop a measure of " intelligent " behaviour. In order to do this programmes have to be written which have intuitive features instead of exact algorithms. This coupled with a vast memory store can make a computer provide answers comparable to those of a human being. To illustrate this detailed programmes are given for machines that play chess and draughts. Also in the first chapter are programmes to prove theorems in logic and geometry, and to solve problems in calculus. The reports on cognitive processes include computer models of human behaviour in solving logic problems.

However, there are omissions. The work would have been more comprehensive if Rosenblatt's work on " neurons " and Widrow's adaptive machines had found a place in the text. But until the subject has had more time to crystallise it is difficult to judge which contemporary articles will have a permanent place in the early history of a wide, and sometimes nebulous, subject. Nevertheless there is sufficient material to tax the mind of the keenest of readers for a very long time. It is not a book to pick up and read from cover to cover. One article alone can take a lot of concentration for its full appreciation.

There is no doubt that the basis of computer technology for the future is contained in this well-written book. **G. Harries**

Dynamical Theory of Groups and Fields. By B. S. DeWitt. Pp. xi and 482. London. Blackie & Son Ltd. 1965. Price, bound 40s., paperback 22s. 6d.

This book, in Blackie's series of Documents on Modern Physics, is a reprint with the addition of an extra chapter, of the sections written by the author in Relativity, Groups and Topology also published by Blackie and Son and edited by C. DeWitt. This latter book, issued in 1964, publishes the lectures delivered in 1963 at the Les Houches Summer School of Theoretical Physics at the University of Grenoble.

The book is an exposition of modern advanced field theory entirely from the mathematical standpoint with no numerical calculations, although this is possible from the theory, but in some cases only with difficulty. Field theory, perhaps through lack of success in the difficult elementary particle field, is perhaps not too popular with advanced experimentalists and one of the author's aims is to attempt to show its real beauty if not its usefulness. Most theoreticians still believe that field theory will play its part in future advancements, but even were this not true, the theory has its own intrinsic beauty if one cares to learn the language.

The other aim of the book is the extension of quantum theory to fields possessing non-Abelian infinite dimensional groups. This mostly original work by the author for whose existence the author stresses there is not a shred of physical evidence. The author claims that with the introduction of these groups some of the fundamental concepts of fields are revealed more clearly. The author has attained both of his objectives in this book.

Field and group theory is now an extensive mathematical discipline and this text is not an introduction to the subject although some chapters can be used as such. The early chapters are concerned with basic field theory; the action principle and functional derivates, the quantum theory as the theory of small disturbances, theories of measurement which connect the theory with physical observables, and the uncertain principles in general form.

Group theory plays a central part in field theory and there are chapters on the more standard groups, continuous Lie groups, general co-ordinate transformation groups and the more recent Yang-Mills groups. Lie groups and Lie algebras are finding wide application in physical theory, including microwave theory.

A number of specific Lagrangians are discussed such as that for the gravitation field, Yang-Mills field, multicomponent scalar fields, and combinations of these. Spinor fields are also included. The last chapter, which covers work done since 1963, extends the work started by Feynman on the quantisation of non-Abelian infinite invariance groups, such as the gravitational field (and treated more simply by the author in the earlier chapters of this book), to the problem of higher order radiative corrections in perturbation theory.

The book, although in no sense an elementary text, is good value for anyone interested in field theory and has the adequate mathematical background to peruse it.

R. A. M. Bound

The Dynamics of Conduction Electrons. By A. B. Pippard. Pp. 150. London. Blackie & Son Ltd. 1965. Price 32s. 6d.

This book is based on lectures given at the University of Grenoble's Les Houches Centre for the study of physics in 1961. The author sets out to reveal the physical processes involved in electronic phenomena by the use of only elementary mathematics; it is very remarkable that he achieves this aim without any gross oversimplification. The main phenomena considered are the anomalous skin effect, galvanomagnetic phenomena, de Haas-Van Alphen effect, acoustic attenuation and cyclotron resonance. A central theme of the book is the relation of these phenomena to the geometry of the Fermi surface.

The author's approach is almost invariably semiclassical, being based on the Boltzmann equation, but he questions the validity of this approach whenever necessary. In fact it is fascinating to find that the classical method often works far beyond its expected range. The assumption of a relaxation time in the Boltzmann equation is also treated with due caution. A brave attempt is made to assess the role of electron-electron interaction in the phenomena considered but this is inevitably the least satisfactory section of the book.

One cannot help regretting that the only addition to the text made since 1961 is one page of notes and references—but this is ungrateful. In this book Professor Pippard permits us an insight into his personal mode of thought about electronic phenomena, a mode of thought which has proved immensely fruitful. The book is essential reading for all who wish to increase their understanding of the behaviour of electrons in metals.

D. M. Edwards

Principles of Physical Oceanography. By G. Neumann and Pierson Jnr. Pp. xii + 545. London. Prentice Hall International Inc. 1966. Price 180s.

Oceanography is one of those natural sciences which is at present undergoing an accelerating interest on an international scale. The current decade is witnessing the advent of large scale ocean surveys, specially designed research ships, underwater laboratories, with bathyscaphes penetrating much greater depths than were hitherto conceived possible. It is quite understandable that with North Sea borings for oil and natural gas at present in progress and the exciting prospect of underwater activities such as fish-farming and exploiting new mineral sources, that a demand should exist for appro-

priate text books. Whilst there is considerable specialist literature in the relevant journals, obviously there is a need to satisfy the interest of scientists in other disciplines and for undergraduates who need some comprehensive introduction to a subject which is allied to the particular disciplines they are studying.

The authors state that they are trying to satisfy the needs of three types of reader, the senior undergraduate who has decided to specialise, the graduate in another discipline who finds there is "a need to know," and those scientists and engineers with a general scientific interest and require a convenient reference book. By compiling a book midway between an elementary introduction and a high level treatise for the specialist, the authors have succeeded in the main in fulfilling their aim.

When writing such a book of this comprehensive nature, some duplication of standard material or insertion of chapters explaining some special mathematical techniques is often unavoidable. The authors expect their readers to have covered what amounts to the first two years of a B.Sc. General Degree course, and yet we find a whole chapter dealing with the hydrodynamic equations, a topic usually covered in a science undergraduate's course, at least by the end of the second year. Furthermore, a special chapter has to be devoted to Probability Theory, Statistics and Times Series. These 'insurances' tend to give the treatment a somewhat unbalanced aspect.

After a very interesting introductory chapter on the history of oceanography, the following topics (in addition to those mentioned above) are treated; the ocean bottom, properties of sea water, ice, means of data collection and processing techniques, mechanics of ocean currents, tides, wave motion, turbulence and circulation. The book concludes with an appendix of tables and a very comprehensive bibliography. The printing, format and diagrams are of a very high quality, all this provided a very wide coverage. Nevertheless, the reader is made aware of the most interesting and really basic research done in the last century, work that has been embellished, rather than fundamentally adjusted. Furthermore, the most interesting current modern research is made available, enhanced by first class photographs and diagrams.

From the point of view of the Naval Scientist who specialises in the underwater field, this book is probably too elementary, but for other scientists (Naval and otherwise), this book can be of tremendous interest and appeal, as well as providing a convenient reference book.

W. E. Silver

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